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Effectiveness of Stop Sign Installations at Highway-Railroad Grade Crossings: An Evaluation of Installation Safety Performance

Harold Lynn Millegan
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Harold Lynn Millegan entitled "Effectiveness of Stop Sign Installations at Highway-Railroad Grade Crossings: An Evaluation of Installation Safety Performance." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

Lee Han, Major Professor

We have read this dissertation and recommend its acceptance:

Stephen H. Richards, Arun Chatterjee, Xuedong Yan, Bruce Ralston

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Effectiveness of Stop Sign Installations at Highway-Railroad Grade Crossings: An Evaluation of Installation Safety Performance

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Harold Lynn Millegan
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ABSTRACT

The safety benefit of Stop-sign treatment employed at passive highway rail crossings has been a subject of research for many years. The objective of this study is to assess the effectiveness and impacts of Stop-sign treatment on crossing safety. This research addresses safety at public highway-railroad grade crossings across the United States within a 26-year period of accident history for Crossbucks-only controlled crossings that were upgraded to Stop-sign control.

This study utilized Federal Railroad Administration (FRA) accident data to investigate average accident frequency at crossings with the two different types of passive-crossing sign controls. The research database was created by locating and extracting records relevant to public crossings, excluding private, pedestrian, and grade-separated crossings.

The research followed a three-part approach. The first part of the study used statistical analysis methods to evaluate accident frequencies for target crossings. Analysis of accident frequencies that occurred during both phases of installation history indicates that accidents were significantly lower during the Stop phase than during the Crossbucks-only phase.

The second part of the research used logistic regression modeling to further evaluate accident risks and factors at these two types of passive railroad grade-crossing treatments. Results of the logistic regression were reported according to the main effect of various factors and variation of those factors. An analysis of covariance was performed between factors of statistically significant contribution.

The third part of the research synthesized data into a set of models designed to predict safety performance of Stop signs and Crossbucks. Negative-binomial regression modeling was used to identify attributes and limits for which Stop signs showed superior safety benefits.

This research concludes that Stop controls did lead to discernable reduction in the accident rate, particularly for the period since ISTEA (1991). Annual accident frequencies were significantly higher during the period when crossings were controlled by Crossbucks only.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

CHAPTER 1: INTRODUCTION

"The care of human life and happiness … is the first and only objective of good government."

Thomas Jefferson

President Jefferson's quote is very similar to the first Cannon of Ethics for engineers:

"The engineer's paramount responsibility is the safety, health and wellbeing of the general public."

Engineers Code of Ethics

It should not be construed from the above statements that engineers are responsible for human life and happiness. However, if the engineer does not meet the first cannon's requirement for safety, health, and wellbeing of the general public, human life and happiness are difficult to attain.

This dissertation is about safety; specifically, highway-railroad grade-crossing safety. Its focus is on the impacts of Stop signs used at highway-railroad grade crossings. The objective is to examine the safety record to determine if Stop sign augmentation of Crossbuck-controlled crossings has had an impact on safety as evidenced in the accident record of road users at public, passive, highway-railroad grade crossings.

1.1 Background

Vehicle-train crashes are the most dangerous traffic accidents at highway-railroad grade-crossings. The average weight ratio of train to automobile is about 4,000 to one.(1) Such a huge mass difference results in a great injury/fatality rate in train-automobile crashes. Therefore, compared to highway intersections, although the annual crash frequency of grade crossings is relatively lower, rail-highway grade-crossing safety issues are critical.

Highway-rail grade crossings are generally categorized as two groups, namely active and passive.(2) Active grade crossings use devices to detect approaching trains and warn motorists by initiating sequences of flashing lights, bells, and/or gate closures. Passive grade crossings do not detect approaching trains. Instead, motorists must take notice of the passive controls (signs and markings), understand what they mean, listen, search for trains, and respond appropriately.

During the past 30 years, the annual accident rate has significantly decreased at rail-highway grade crossings. However, this reduction has come about largely through improvements to the level of grade-crossing control (i.e., flashing lights, automatic gates, grade separation), as well as through improvements to active warning devices. For passive crossings, there has been no clear improvement in driver behavior or crash experience.(3)

The *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance on what traffic-control devices (TCDs) should be used at public-passive rail-highway grade crossings. As a minimum, one Crossbuck sign shall be used on each highway approach to every highway-rail grade crossing, alone or in combination with other traffic-control devices in order to mark the location of the railroad tracks at the point where they cross the road.(2) Stop signs should be used at the discretion of the responsible State or local highway agency if highway-rail grade crossings have two or more trains per day and are without automatic traffic control devices. The optional TCD treatment at passive crossings includes a Yield sign or a Stop sign. Yield signs have not been frequently deployed at rail-highway grade crossings (3), and no research appears to have been done comparing Yield signs to Crossbucks at crossings.(4)

Engineers and policy makers who make decisions about traffic-control posting configurations are not in complete agreement on whether Stop signs are effective when used at highway-railroad grade crossings. The safety benefit of Stop-sign treatment employed at passive crossings has been a controversial focus point for many years. NCHRP Report 470 indicated that there were differences of opinion regarding the use of Stop signs at passive grade crossings including don't use at all, use only under certain conditions, and use at all passive crossings unless hazardous.(3)

The use of Stop signs was authorized by the Intermodal Surface Transportation Efficiency Act (ISTEA) (5) and the Federal Highway Administration.(6) A prior study reported that upgrades from no signs or Crossbucks-only to Stop signs significantly reduced accident rates at both low-volume and higher-volume highway-rail grade crossings.(7) The National Transportation Safety Board (NTSB) suggested a broader use of Stop signs at railroad-highway grade crossings and recommended Stop signs as an interim device until intelligent transportation systems are developed to warn the driver.(8) Sanders, et al., found that Stop signs were used more frequently in urban areas and that crossings having Stop signs tend to have higher train volumes; accident rates for Stop-sign crossings were lower than those for Crossbuck-only crossings for higher vehicle-train exposure values; and Stop signs, when properly used, resulted in improved driver behaviors adequate for the detection and avoidance of trains.(9) They suggested that Stop signs should be applied selectively, only at hazardous passive grade crossings rather than indiscriminately at all passive grade crossings. Additionally, in Canada it was found that Stop-sign countermeasure can improve crossing safety performance by as much as 35%.(10)

On the other hand, other researchers did not suggest the use of Stop signs because observational studies showed that motorists frequently disregarded Stop signs at grade crossings.(11, 12) If the Stop sign were used indiscriminately (3), the high level of noncompliance might increase and carry over to other locations. These observational studies showed that the percentage of drivers not coming to a complete stop at grade crossings was higher than the percentage who did not come to a complete stop at highway intersections. Evidence was lacking to support the claim that a high noncompliance rate correspondingly leads to a high accident rate at Stop-controlled crossings.

A recent study examined 10 years of collision data in seven Midwestern states using the FRA accident database and compared collision rates among four types of crossings: Crossbucks, Stop signs, flashing lights, and gates.(4) The collision rate calculation was based on millions of crossing vehicles, the average number of daily trains, and the product between them (exposure factor). It was reported that compared to other types of crossings, collision rates for crossings with Stop signs were much higher, especially when using millions of crossing vehicles as the collision rate calculation base. However, those collision rate calculations neglected other significant risk-evaluation factors, such as number of tracks, road surface type, and train speed, which are often used to investigate effectiveness of countermeasures at grade crossings.(13, 14)

The safety benefit of the Stop-sign treatment employed at passive crossings appears still unresolved and controversial. Thus, one question is what happens at crossings where a change is made from Crossbucks to Stop signs. The before-and-after and cross-sectional statistical analysis methods are well accepted tools, well understood, and have been used to evaluate the effectiveness of a countermeasure on highway safety by a number of researchers.(15, 16, 17) In these studies, the effectiveness of specific countermeasures is determined by comparing collisions at each crossing before and after their introduction. Additionally, planners and decision makers have not had a statistical assessment model that allows them to select significant input risk factors and be able to assess benefit of using a Stop-sign countermeasure at specific grade crossings.

As will be discussed herein, a unique and statistically robust approach was developed and used, which resolves many of the inherent problems normally associated with evaluation of Stop-sign effectiveness at passive crossings.

1.2 Statement of Problem

Do Stop signs improve safety at highway-railroad grade crossings compared to Crossbucks-only, where the safety of an entity is defined as *"the number of accidents by type and severity expected to occur on the entity in a certain period, per unit of time"* ?(15)

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) was enacted by the U.S. Congress. In Section 1077 of ISTEA, the Secretary of Transportation was directed by Congress to:

> *"Revise the Manual of Traffic Control Devices (MUTCD) to authorize States and local governments, at their own discretion, to install stop or yield signs at any rail-highway grade crossing without automatic traffic control devices with two or more trains operating across the crossing per day."*(5)

Before ISTEA, a major question about passively controlled grade crossings was whether a Stop sign or Yield sign was more effective. Winans noted that prior to ISTEA, "*. . . the MUTCD limited the use of Stop signs to those rail-highway grade crossings selected after a need was established by a detailed traffic engineering study, and Yield signs were not accepted as an appropriate traffic control device at rail-highway grade crossings."*(18)

Some members of the highway safety community believe that posting Stop signs at grade crossings is like crying “wolf”; if a train is not observed on a regular basis at the crossing, motorists will come to regard Stop signs as having less meaning than the law intends.(4)

Even though the usage of these controls had been enacted into law by a Congress anxious to provide additional options to address the continuing safety problem at public grade crossings, their effectiveness still remained undocumented. Controversy still exists in the literature and in practice whether Stop signs significantly enhance safety at passive highway-railroad grade crossings.

1.3 Research Objectives

This research seeks to:

1. Statistically evaluate accident frequencies during both Crossbucks-only and Stop-sign treatment phases of crossing history.
2. Statistically evaluate significant factors associated with crossings and accidents and the propensity (or natural inclination) of drivers to experience accidents after Stop-sign treatment was added.
3. Build statistical models to analyze and predict annual accident frequencies for both types of passive grade crossings studied.

In the 1970’s the Federal Railroad Administration began keeping records of train-related accidents across the entire United States, resulting in a large safety-record dataset available for analysis that begins well before and extends well after the 1991 ISTEA legislation. With approximately 38 years of accident data available, and with Stop-sign and Crossbuck-only usage recorded during that time period, accident propensities at these configurations can now be examined on a nationwide scale over a significant time period.

Allowing a10-year period from 1970 to 1980 for data input to the FRA dataset to stabilize and for data reporting procedures to mature (i.e., relatively complete, unambiguous, accurate and stable), this research examines the train-related accident record in the United States from 1980 forward.

CHAPTER 2: LITERATURE REVIEW

In following sections, the concepts of danger and safety, highway-railroad grade-crossing safety risks, treatment of risks, controversy that exists in the literature, and previous research regarding the usage of Stop signs at highway-railroad grade crossings will be presented.

2.1 Background

Railroads predated the automobile and played a vital role in the settlement and economic development of the nation. Towns and cities sprang up beside railroad tracks, and city street patterns often were formed parallel and perpendicular to them.

New modes of transportation evolved out of trade between towns and cities. Over time, as need intensified and range expanded, more and more people and vehicles were brought into closer contact.

At first, the crossing of railroad tracks was relatively easy and involved little conflict, except for the occasional frightened horse. But in the late nineteenth and early twentieth centuries, the motorcar was introduced and its popularity resulted in an ever-increasing number of vehicles on the roadways.

If uncontrolled, the consequence of close contact of frenzied activity is conflict. With urbanization came an increase in vehicle velocity and number of vehicles in close proximity, resulting in an increase in property damage, injuries, and crash fatalities. Current issues in road transport safety arose from this successful mass production of the private automobile.

Transportation accidents, as crashes were previously called, did not begin with the modern vehicle. Over 100 years ago, Bortkiewicz published accident studies in his book titled “The Law of Small Numbers”.(19) Bortkiewicz’s study of horse-kick accidents precipitated the first of several road-transport safety theories (Random Events Theory) leading to the most recent approach − Behavior Theory**.**

Mathematicians, psychologists, physicians, and others have studied accidents and made contributions to the realm of road transport safety. Their focus was to explain the phenomenon of the occurrence of accidents using examples of their research in accident theory.(19, 20, 21)

2.1.1 Automobile Impact on Transportation Safety

In general over the twentieth century, the United States enjoyed a declining mortality rate: health improved, daily activities of life were easier to accomplish, and there was greater opportunity for leisure. (A crude plot of the mortality rate in the United States during the twentieth century, reflecting deaths per 1,000 in population, is provided in Figure 1.)

However, traffic mortality frequencies during the same time period reveal a different picture. Figure 2 shows the annual mortality (deaths per 100,000) due to traffic crashes for the twentieth century. The fatality rate due to injuries in road

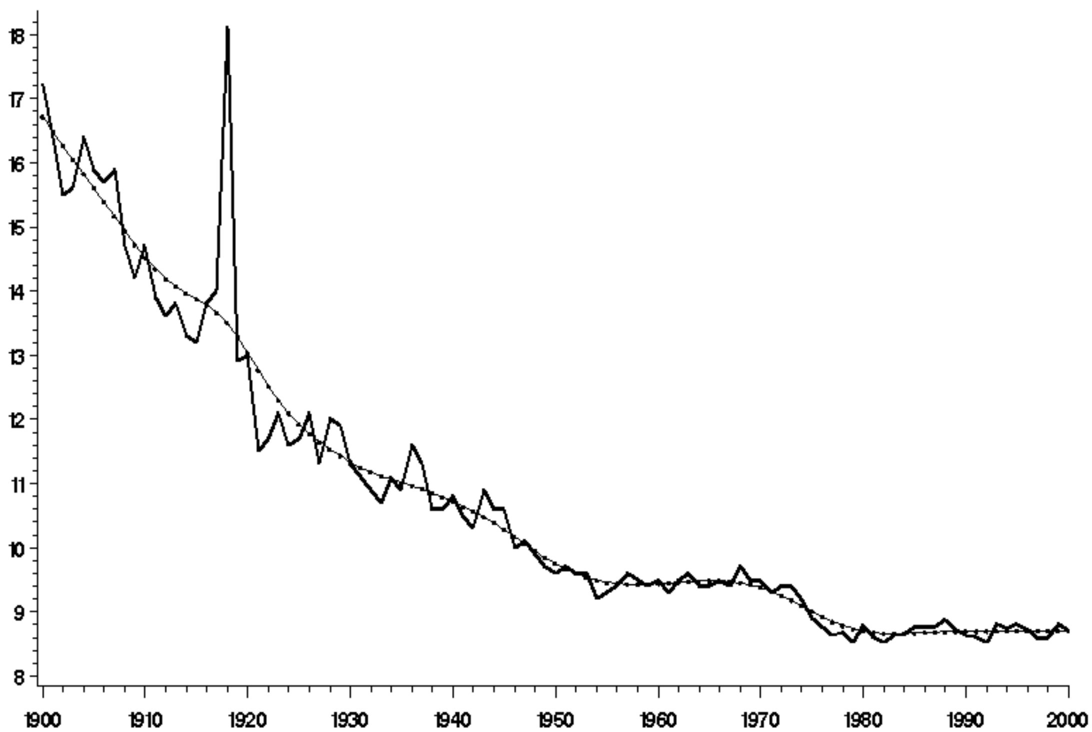


Figure 1: Crude mortality rate in the United States during the 20th century, deaths per 1000 population. The thin dotted line is a Hodrick-Prescott long-term trend line computed with a smoothing parameter equal to 100. (2)

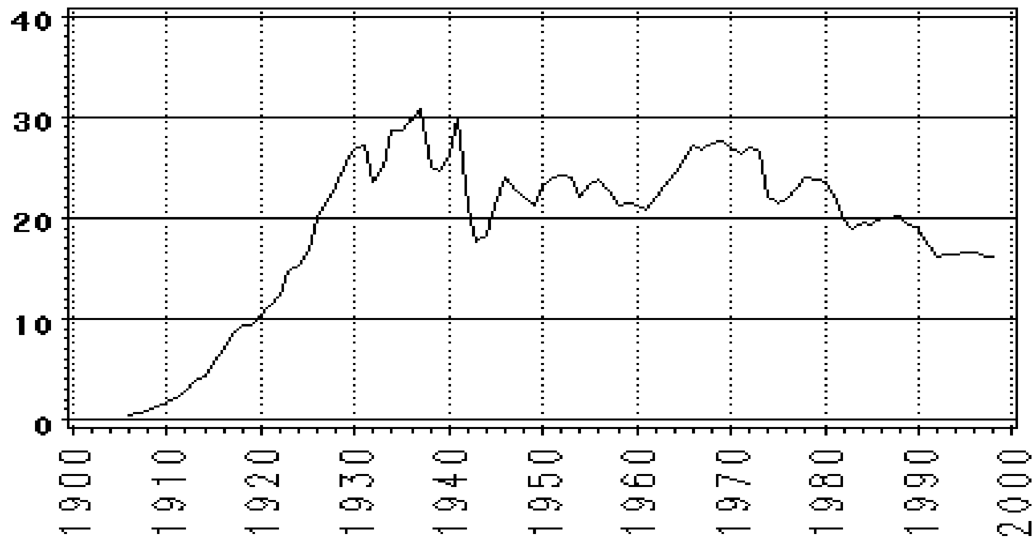


Figure 2: Annual mortality (deaths per 100,000 population) due to traffic crashes(22)

transport crashes grew across the entire century, a phenomenon in the reverse of the general mortality rate for that time period.

Hinrichs, in his history of James Cunningham, Son and Company that once made carriages, notes that the automobile made its début in America in the late 1890s as an import from Europe.(23) He goes on to say that the automobile began as a toy for the wealthy, and that the automobile age didn't begin in earnest until 1919. Automobiles emerged on the world stage during World War I when Peugeot taxis carried men to the front from Paris and Model T Fords found their place on the battlefield as field cars.

In 1919 there were about seven million cars in the United States. Barker (24) notes that motor vehicles were developed initially to mechanize local transport, as the steam railway had earlier mechanized it over longer distances.

Barker relates that by 1920, just after the War, “the spread of motoring was soon influencing family expenditure and social habits.”(24)

Examining Figure 2, one can see that the downside of vehicles was already occurring in the early days of the twentieth century. The most dramatic period was from the introduction of the automobile around the turn of the century to a peak in the mid-1930s. Chatburn (25) says that at the beginning of the 1920s, one motorist in seven was annually involved in an accident resulting in vehicle damage, personal injury, or death.

The fatality growth trend in the early part of the twentieth century is associated with the rapid expansion of the new automobile technology and is shown on Figure 3. During this time drivers were inexperienced and vehicles were often unreliable.

2.1.2 Railroad-Crossing Safety

Accidents occurred at grade crossings as early as the latter half of the nineteenth century. These conflicts began more in favor of the carriages but proceeded in favor of the train as engine and car mass increased toward the end of the century. The same mortality trend seen in the early part of the twentieth century with regard to the surge in motorcars, was also seen at highway-railroad grade crossings. Shaw notes that:

> *“This relative immunity from highway crossing danger which trains enjoyed for half a century and longer began to diminish in the*

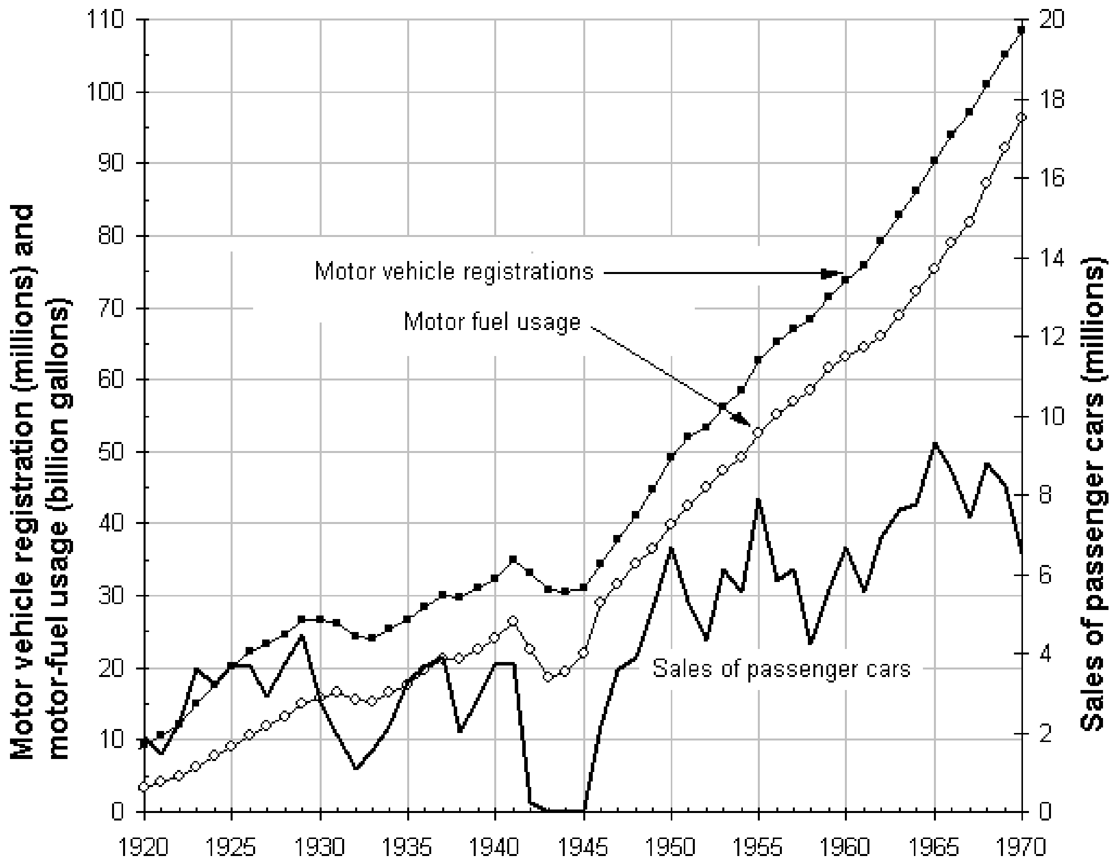


Figure 3: Three indices of motorization of the U.S economy, 1920-1970(22)

> *1920s as the previous trickle of motor vehicles at grade crossings swelled into a stream."*(26)

Shaw goes on to relate that one of the largest violators seemed to be large trucks, which he attributes to the "typical carelessness of the truck driver".(26) He indicates that:

> *"Locomotive engineers have had to contend with numerous gasoline and fuel oil tank trucks, as well as with a wide range of flat bed trailers, bulldozers, cranes, power shovels, earth scrapers and other ponderous equipment, crossing the tracks . . . tank truck drivers seem to show a marked proclivity, perhaps stemming from a desire to live dangerously, to enter crossings just ahead of speeding trains."*(26)

The mortality surge that Shaw speaks of can be readily seen from the data plotted on Figure 4, indicating fatalities at public grade crossings between the years 1920 and 2004. This figure shows that there was a surge in grade crossing mortality in the 1920s followed by a steady decline, another surge in the 1960s and 1970s, and then another decline to 2004.

Looking at the trend shown over the same time period on Figure 5, one can see that the highway-fatality rate increased slightly over the period, but decreased at railroad crossings. Not shown is the sky-rocketing number of vehicles and highway miles over the period. When this is considered, along with safety programs instituted during that time, one can see attenuation was had in both categories.

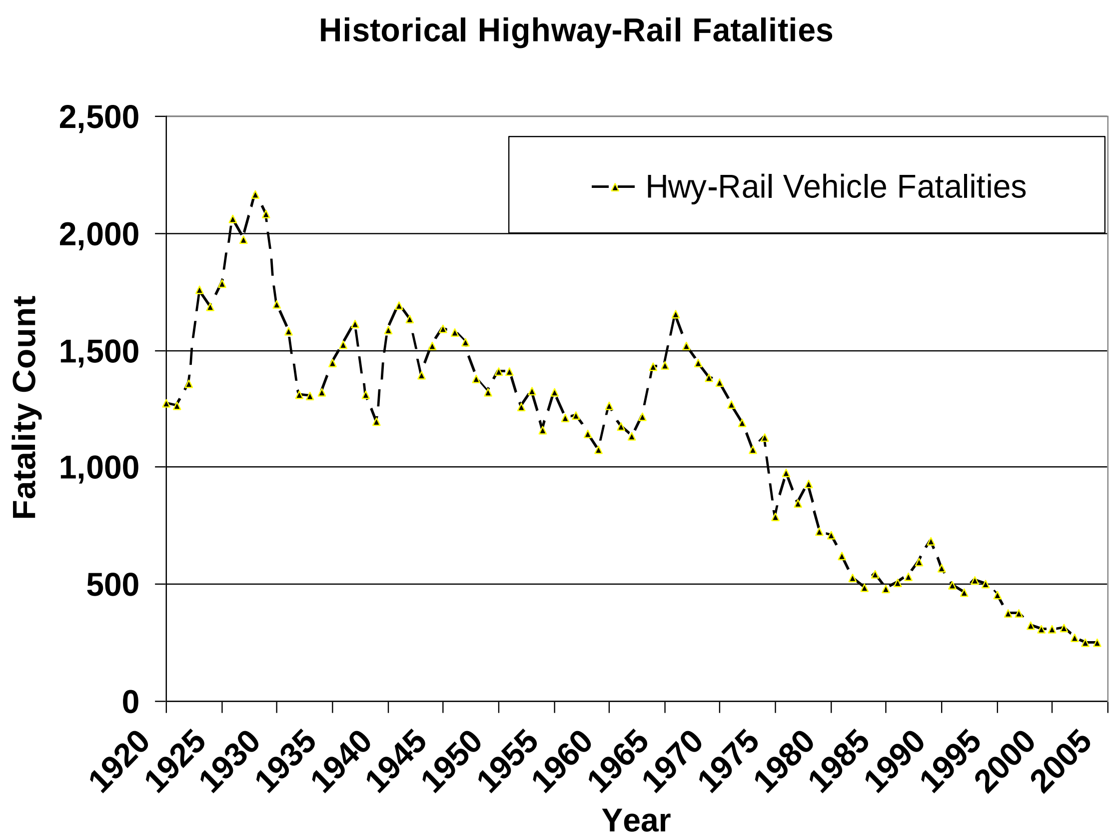


Figure 4: Fatalities at public grade crossings, 1920-2004(27)

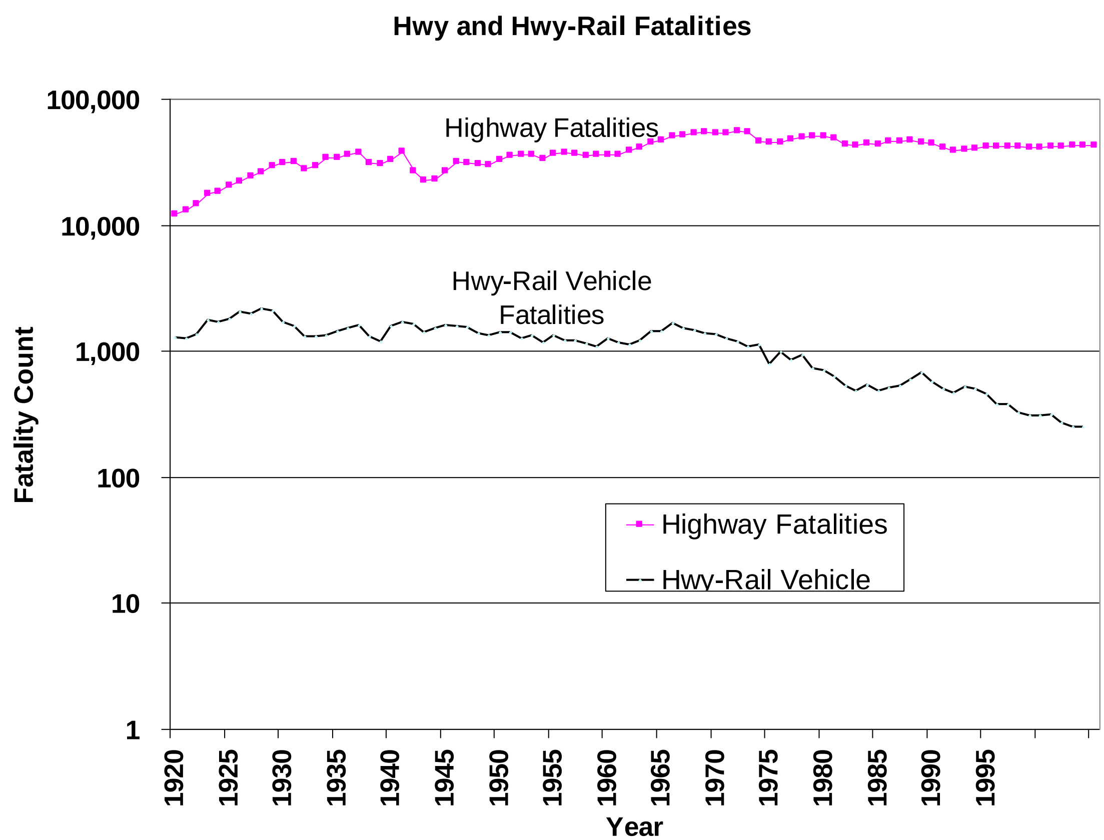


Figure 5: Highway fatalities and highway-rail fatalities at public grade crossings in logarithm scale, 1920-2004

By the 1980s, substantial safety improvements steadily resulted in decreased traffic mortality. Because engineering improvements, such as vehicle and infrastructure safety features, made travel safer, highway fatality trend remained steadily downward until the early- to mid-1990s. Over the last 10 years, highway mortality has remained relatively constant in the United States at approximately 43,000 fatalities per year, with only a slight upward trend; however, highway-railroad grade-crossing accidents and fatalities continued to drop.

2.2 Safety, Danger, and Risk

2.2.1 Concepts of Safety and Danger

Road transport safety is a global issue, becoming a major cause of death and serious injury. Merriam Webster describes “safe” as an adjective that means “secure from liability to harm, injury, danger, or risk.” “Safety” is described as a noun that means “the state of being safe; freedom from the occurrence or risk of injury, danger, or loss.”(28)

In Traffic Flow Theory Monograph, the safety of an entity is defined as “the number of accidents by type, expected to occur on the entity in a certain period, per unit of time.”(29) According to this definition, safety of an infrastructure correlates with frequency and/or opportunity for the occurrence of crashes. By these definitions, the basic philosophy or concept of roadway-vehicle transportation-system safety is based on risk − risk taken by users entering the system, risk involved in mingling with other users, and risk in following certain routes.

Hauer (15) suggests that safety can be understood through an alternative approach that is seemingly antithetical − danger, as demonstrated on Figure 6. Each accident is preceded by a dangerous situation that, in turn, is preceded by incipient danger that stems from normal traffic. Each level of danger builds on the previous level in such a manner that the risk continuously grows until triggered into an accident.

Using this antithetical approach, one can see that risk exists in normal traffic that leads to incipient danger. Safety is related to danger through risk that ultimately precipitates "the number of accidents by type, expected to occur on the entity in a certain period, per unit of time" (15), and, therefore, can be thought of as a measure of danger.

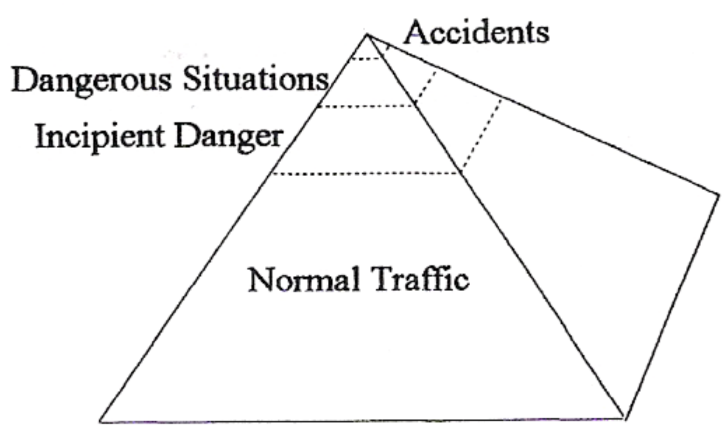


Figure 6: Continuum of events leading to danger and accidents(15)

Generally speaking, crashes occur when vehicles move out of the locus of a controlled trajectory into conflict with another object, pedestrian, or the earth. In the case of highway-railroad grade crossings, this occurs when a vehicle traveling on the road crosses into the path of an oncoming train.

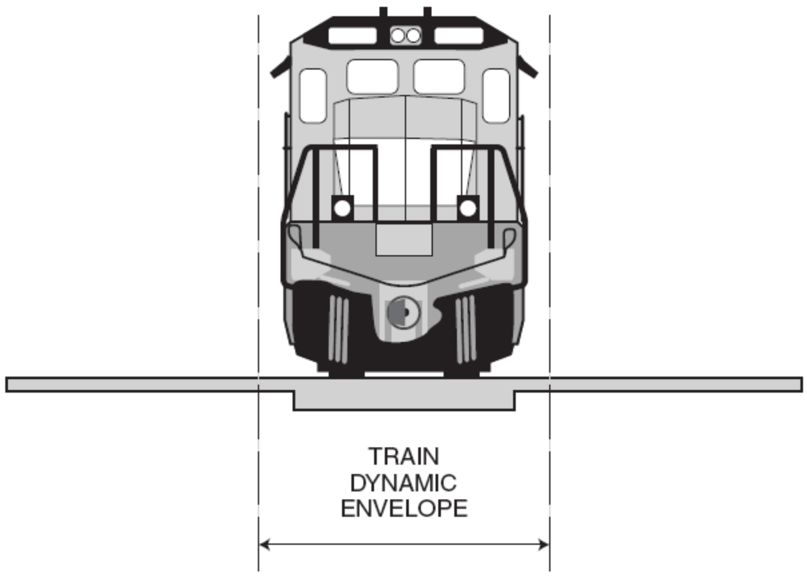
Trains are massive and because of momentum and braking limitations they may need a mile or more to come to a complete stop. Because of their momentum and large mass, we can see through means of the energy equation ($E= 1/2\ mv^2$) that a tremendous amount of energy exists. Whenever there is more energy in the system than can be safely attenuated, an unsafe condition (danger) exists. When stopping, the energy that is not dissipated in braking goes into whatever is occupying its path, more specifically the dynamic envelope or the space influenced by the train along its axis, as shown on Figure 7.

2.2.2 Safety Risks

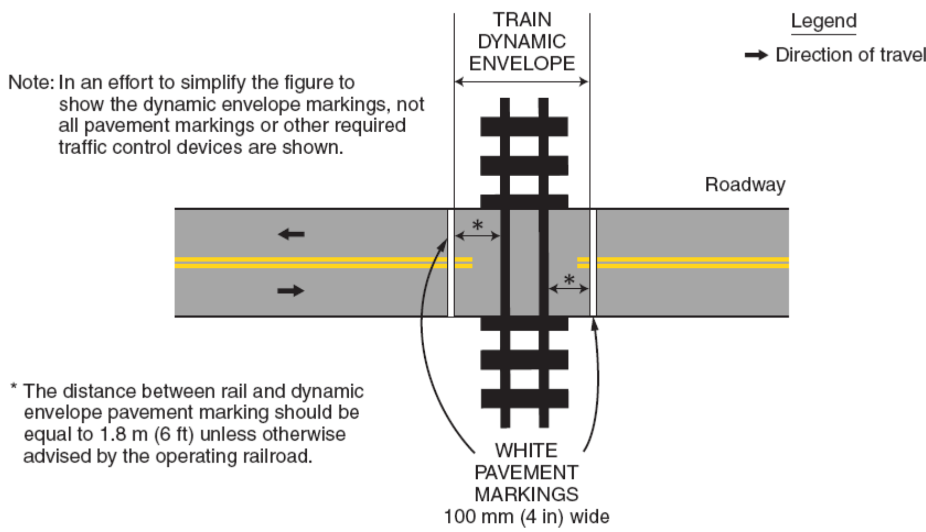
Many risks are associated with negotiating highway-railroad grade crossings. As Haddon's matrix (20) suggests, at every crossing the fundamental road-transport system is composed of four interactive elements: the user (human), the vehicle, the infrastructure, and the environment. Epidemiologically, Systems Theory says each element has some contribution to risk at a crossing.

To safely negotiate a highway-railroad grade crossing, a motorist must accomplish the following:

1. Be aware of and see the crossing
2. Understand their duty



(a)



(b)

Figure 7: Train dynamic envelope: (a) train dynamic envelope and (b) typical markings of dynamic envelope(2)

3. Search for approaching trains
4. Reduce speed, as necessary, to be able to stop when a train is seen
5. Begin to brake in time to stop before the dynamic envelope

For instance, motorists unfamiliar with an area may be unaware that a crossing exists or motorists may expect grade crossings to be equipped with signals and automatic gates that warn of the imminent approach of trains. Richards and Heathington noted that in a survey of 211 Tennessee drivers:

> *"twenty-two percent of the drivers believed that all grade crossings had active control warning devices. Sixty-two of the very young drivers (16-18 years) thought that all crossings had active warning devices."*(30)

Other potential risks stem from the fact that in rural areas, vegetation often obscures visibility. And in urban areas, development can be found along roadways near grade crossings that obscures driver vision of the tracks.

In summary, risk that directly inhibits the driver's ability to successfully negotiate highway-railroad grade crossings includes, but is not limited to:

1. Driver knowledge of the crossing
2. Driver understanding of the duty to stop
3. Obscured vision of approaching trains
4. Driver speed behavior and ability to be able to stop when a train is seen
5. Driver braking behavior and ability to stop before the dynamic envelope

2.2.3 Treatment of Risks

Grade separation provides the safest solution for negotiating a highway-rail crossing by eliminating mass-disparate vehicles vying for occupancy of the crossing. But, where grade separation is not possible or practical, most grade crossings are controlled with active or passive devices to provide warnings and restrictions for motorists. Each traffic-control device conveys a specific meaning of warning, guidance, or regulation. Motorists must see, respect, and heed these signs to safely negotiate the driving environment. Standard Crossbuck and minimum Stop-control configurations are shown on Figures 8 and 9, respectively.

Active grade crossing devices detect approaching trains and warn motorists by initiating sequences of flashing lights, bells, and/or gate closures. Passive grade crossings do not have devices that detect approaching trains. Instead, motorists must take notice of the signs and markings, understand what they mean, search for trains, and then respond appropriately.

Section 1A.02 of the MUTCD, Principles of Traffic Control Devices, states:

"To be effective, a traffic control device should meet five basic requirements:

A. Fulfill a need;

B. Command attention;

C. Convey a clear simple meaning;

D. Command respect from road users; and

E. Give adequate time for proper response."(2)

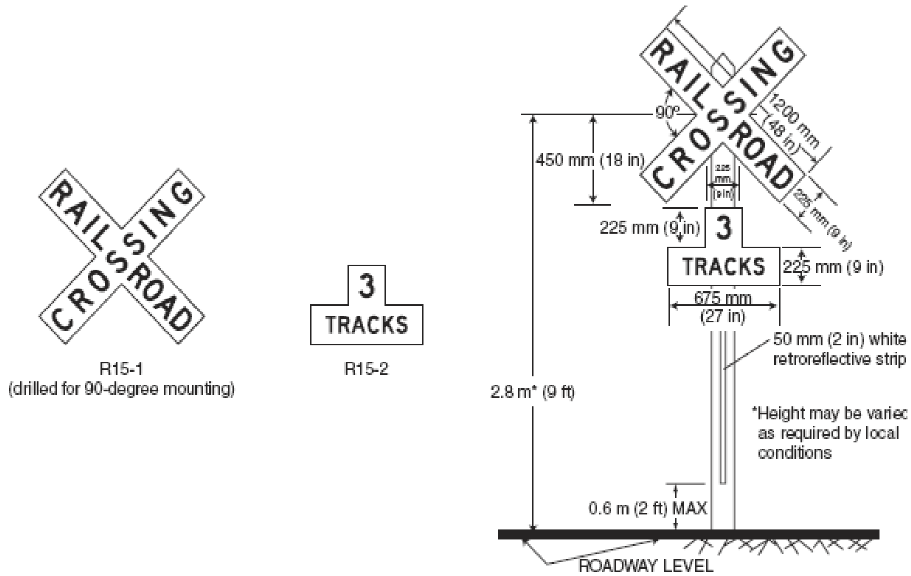
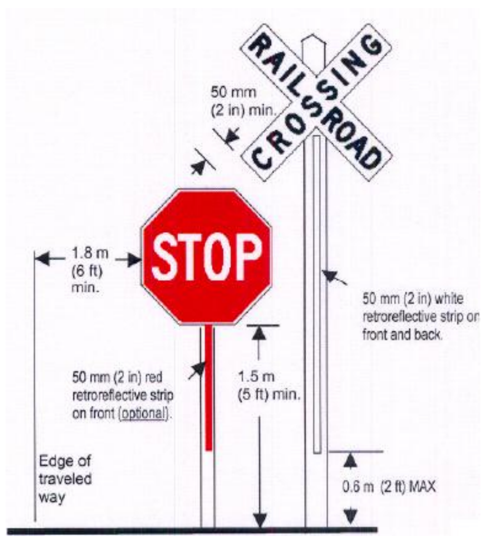
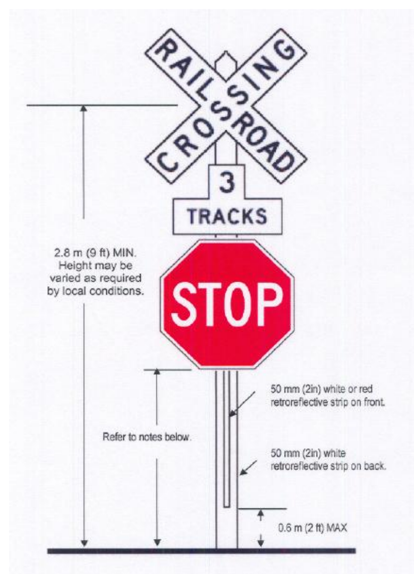


Figure 8: Standard Crossbuck and supplemental number of tracks signs(2)



(a) Separate Mounting



(b) Common Mounting

Figure 9: Standard Crossbuck with Stop sign on separate mounting (a) and Stop sign and supplemental number of tracks sign mounted on Crossbuck post (b)(2)

Part 8 of the MUTCD states that: "the combination of devices selected or installed at a specific highway-rail grade crossing is referred to as a 'traffic control system'".(2)

2.3. Behavior at Intersections

Recently, Stop signs have become more common at highway-railroad grade crossings, but they are a commonly used regulatory traffic-control device at roadway intersections. This section reviews some of the literature regarding motorist behaviors at Stop-controlled highway intersections.

Retting, et al., (31) completed research of Stop-controlled intersection violations by reviewing police reports of 1,788 crashes from selected areas. Two thirds of the drivers reportedly came to a stop before proceeding into the intersection, while 17 percent admitted to neglecting to stop. Failure to see another vehicle (44%) and obstructed vision (16%) were reportedly the most frequent reasons for a vehicle to proceed into an intersection in the presence of another vehicle.

Liu (32) completed a study to determine contributing violation factors. Liu noted that numerous decisions must be made as a driver approaches an intersection, and that the speed at which a driver is traveling when arriving at the intersection is a large determinant as to how the driver reacts. Through a database analysis, Wang and Knipling (33) reported that most intersection-related crashes occur when the posted speed limit is 35 mph or less. Yang and Najm (34) reported from their research that a majority of crashes occurred at around 18 mph with an average speed of 32 mph. Similarly, Chovan, et al., (35) reported that a number of the crashes occurred on urban roads with lower speed limits.

Both Pierowicz, et al., (36) and Tijerina, et al., (37) have presented causal factors that imply a deliberate disobedience of traffic-control devices. In the survey, drivers were provided with a “go/no-go” scenario in which the “go” decision could be interpreted as aggressive. Twenty-nine percent of the drivers opted to take the aggressive action. Of those drivers, 69 percent indicated that their motivation was to save time and 12 percent reported doing it out of frustration. Of surveyed drivers, 99 percent acknowledged the dangers of red-light running.(38)

The decision to run or attempt to beat a traffic signal (or a train through a grade crossing) might be based on failure to see cross traffic (train); misjudgment of velocity, distance, or direction associated with the perceived traffic (train); the assumption that other vehicles will yield to the violating vehicle; or a belief that a collision can be avoided.

2.4 Review of Selected Grade-Crossing Research

Motorist behaviors have been studied for highway-railroad grade crossings as a distinct group like those in the previous section for roadway intersections. Abraham, et al., (39) studied driver behavior at 37 grade crossings in Michigan, revealing significant violations of traffic-control devices. They noted that, at a 95 percent confidence level, multi-track crossings of multiple road lanes demonstrated significantly more violations and crash counts than sites consisting of multiple tracks and single-lane roadway approaches. They also observed that drivers aged 25 to 40 years committed more violations than drivers in other age groups and that, overall, male drivers offended more than females.

Russell, et al., (40) stressed two key issues in reducing risks at passive grade crossings on low-volume roads: provide adequate sight distance and make the crossings and warning devices conspicuous, particularly at night. The authors also cited the results of a Kansas demonstration project recommending that additional high-performance retro-reflective material be provided at all rural passive grade crossings.

Nam and Lee (41) used a zero-inflated Poisson model to show that highway-rail grade-crossing accident frequencies can be reduced by decreasing the crossing angle, increasing clearing sight distance, increasing warning time, increasing effective lane width, and decreasing average annual daily traffic (AADT) passing through the grade crossing. They list Stop signs as one of several complex interaction variables found, noting that some of these interactions, *(*not necessarily involving Stop signs*),* contribute to accident frequency as a result of train-object impacts, whereas others appear to mitigate the frequency, presumably by altering the driver's awareness in the grade-crossing section.

Carroll and Warren (42) studied photo enforcement at six highway rail crossings across the United States. They stated that the problem at highway-railroad crossings is largely driver behavior and showed that photo enforcement reduced violations in the range of 34 to 92 percent.

CHAPTER 3: RESEARCH METHODOLOGY

This research addresses public highway-railroad grade crossings. Standard statistical methods are used to evaluate the difference in accident frequencies between before and after periods for the target population. The null hypothesis for this study is that there is no difference in accident frequencies for highway-railroad grade crossings controlled by Crossbucks-only and those controlled by Stop signs. The null hypothesis was tested by comparing accident frequencies of the two distributions over the study period.

The research follows a three-part approach. The first part will establish, from accident frequencies during each year of the study period, the overall change in safety since 1980 as the crossings were converted to Stop control. It will test the hypothesis regarding Stop usage safety at grade crossings and establish a general is- or is-not-safer analysis. The second part will develop an accident-comparison model to examine accident attribute distributions of the target population and determine where Stop signs have been most effective. The third part will develop an accident frequency model for the target population in order to predict accident frequency based on crossing attributes where Stop signs have been implemented.

After the three parts have been developed, overall conclusions and recommendations concerning the effectiveness of the usage of Stop-sign installations at highway-railroad grade crossings can be made.

What follows is a detailed description of the methods used in this research.

3.1 Research Data

3.1.1 Federal Railroad Administration Datasets

Local records are difficult to find and, when located, do not effectively combine with other records to form a national database. It is almost impossible to provide a regional, state, and national dataset because each has a unique format. The Federal Railroad Administration (FRA) datasets were identified as the single most complete and accurate datasets available for this research. After these data were obtained, FRA staff who were responsible for data maintenance since 1975 were interviewed. The appropriateness and quality of the data for this research were evaluated. Relevant data were then selected and subdivided for this study.

Three record sets were selected for use:

1. **The Grade-Crossing Inventory database** is a record of the current inventory, as it exists in its current configuration, with one record for each crossing location. Crossing inventory records date from the early- to mid-1970's. Reference attributes in this database reflect the current state of each crossing.
2. **The Grade-Crossing Inventory History database** reflects the date and nature of updates made to the crossing records. Reference attributes

in this database reflect the state changes of each crossing, including a reason for the update and an effective date for the change.

3. **The Grade-Crossing Accident History database** provides a record of accidents that have occurred at the crossings and the conditions at the time of the accident. Reference attributes in this database reflect conditions at the time of a crash.

Generally, these databases are large, flat files. They are not maintained in the most modern database structure, which makes maintenance and coordination between the databases tedious. Descriptions of the variables that are stored in the Inventory and Accident databases can be found in Appendix 1. Although latitude and longitude data are available for crossings, the databases are not spatially enabled for GIS purposes.

Several potential points of confusion were recognized and accounted for. Some duplicates of data are found in the Grade-Crossing Inventory database. Also, records reflected in one database may not be in agreement with records in another because they are maintained separately. For example, it was discovered that entry codes for attribute domains differ between the Grade-Crossing Inventory database and the Grade-Crossing Accident History database.

In like manner, posting updates made by the railroad companies and/or local and state agencies may not always be timely. Consequently, reference attributes that reflect conditions at the time of a crash in the Grade-Crossing Accident History database may not always reflect the state for the same period in the Grade-Crossing Inventory database or even the Grade-Crossing Inventory

History database. The databases are not linked or cross-referenced. The lack of relational or object-oriented design makes examining crossing characteristics challenging.

Crossings generally have two approaches and each may differ greatly in geometry, development, visibility, and other factors. Unfortunately in the inventory, there is only one entry for each crossing rather than one for each approach.

Although Stop and Yield controls at grade crossings have been legal since ISTEA and under certain conditions before then, in the database there is no code to denote Yield controls. This lack is compounded by the fact that entry codes for attribute domains differ between the Grade-Crossing Inventory database and the Crossing Accident History database. An especially careful effort is required in order to not confuse the code domains when evaluating the two together. Potential shortcomings were recognized and accounted for whenever appropriate.

The current FRA grade-crossing inventory contains 406,395 entities split between public, private, and pedestrian crossings. It can be seen from the data that fully 75 percent of the inventory consists of at-grade crossings (361,128), with roughly two-thirds of those being public crossings (214,980). Approximately 50 percent of public grade crossings are controlled by Crossbucks or Stop signs (120,016). Of these, 106,503 (94%) are controlled by Crossbucks and only 13,513 (6%) are controlled by Stop signs.

3.1.2 Data Preparation

This research addresses public highway-railroad grade crossings that are Stop-controlled after having been updated from Crossbucks within the analysis period. Private highway-rail crossings are not included because other factors exist that would present an unclear and inaccurate evaluation of the effectiveness of Stop-sign usage.

The research database was created by locating and extracting records relevant to this research:

1. Public crossings only, excluding private and pedestrian crossings
2. Crossings at grade only, eliminating grade-separated crossings

When a database is being created, it is not immediately operational. There is a period during which the record set is not yet complete or current because data is still being added. Additionally, time is needed for those entering and maintaining the data to become fully familiar with the database's operation. So, for purposes of this research, a beginning date of 1980 was selected. An ending date of 2006 was deemed to be close enough to the present to be completely entered and still current. Thus, this research covers 26 years of accident history.

The relevant records within the FRA databases were divided into four different groups:

1. Crossings controlled by Crossbucks-only throughout the study period (60,024)
2. Crossings controlled by Stop signs throughout the study period (3,628)

3. Crossings controlled by Crossbucks and subsequently upgraded by adding Stop signs (7,394)
4. Crossings upgraded from Stop signs to active controls (305) and all other crossings (active controls, no controls, etc.) (48,665)

Group one consists of crossings that remained controlled by Crossbucks-only during the study period and Group two consists of crossings that were always controlled by Stop signs during the study period; hence, there was no change of control in either group. Because this is a before-and-after study, Groups one and two were culled from the data used in this research. Group four was not applicable to the objective of this study and was also culled.

Group three, however, is comprised of crossings controlled by Crossbucks subsequently upgraded to add Stop signs and shares the same group attributes before and after Stop control was added. Group three, therefore, is used in this research and.

Since each part of the research sought to answer different questions using differing analytical methods, combinations and data formatting were required. The following subsections describe this data preparation.

3.1.3 Data Reduction for Hypothesis Testing

During the study period, 7,394 crossings were found to belong in group three, the target population. These crossings were upgraded nationwide at a rate of approximately 274 sites per year, varying between a low of 63 in 1987 to a high of 890 in 1994. The constant upgrading provided a population of crossings that were in one posting configuration or the other during some portion of the study period. The varying upgrade dates provide sub-groupings with various durations of posting configurations, both before and after upgrade.

The Grade-Crossing Inventory History database was queried to isolate crossings that were converted in each year of the study period. A plot of the number of annual upgrades is indicated on Figure 10. The accumulated number of crossings by type for the target population is shown on Figure 11.

The data for each crossing was divided and analyzed in two time periods: when it was controlled by Crossbucks-only and when it was controlled by Stop signs. At the beginning of the study period, all crossings in the population were controlled by Crossbucks-only. By the end of the study period, all crossings in the population had Stop signs added.

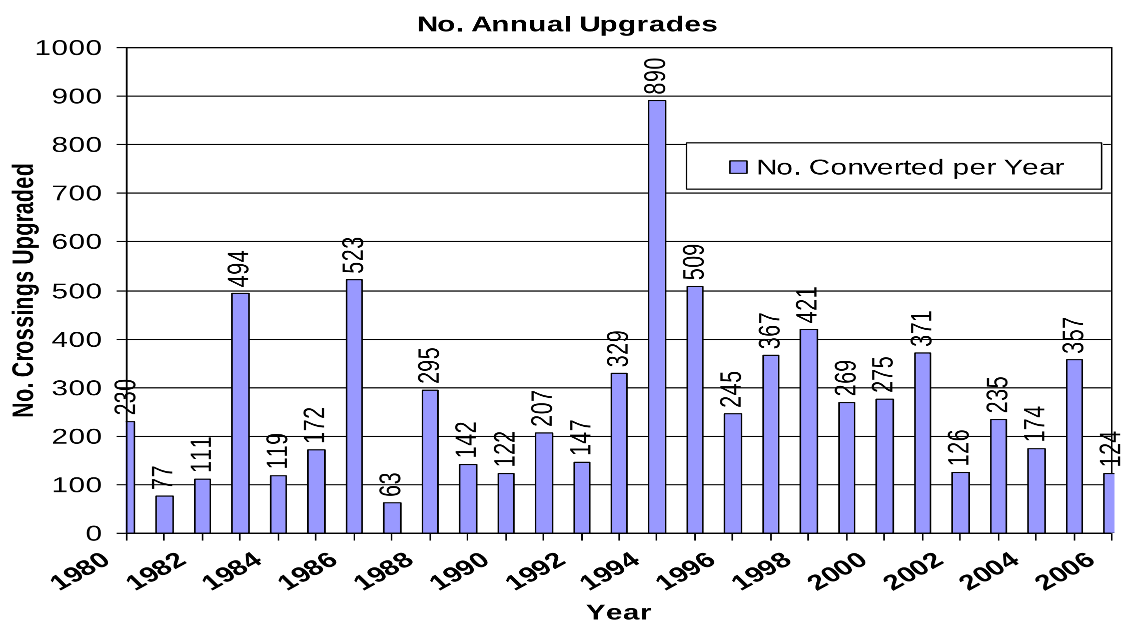


Figure 10: Number of annual crossing upgrades

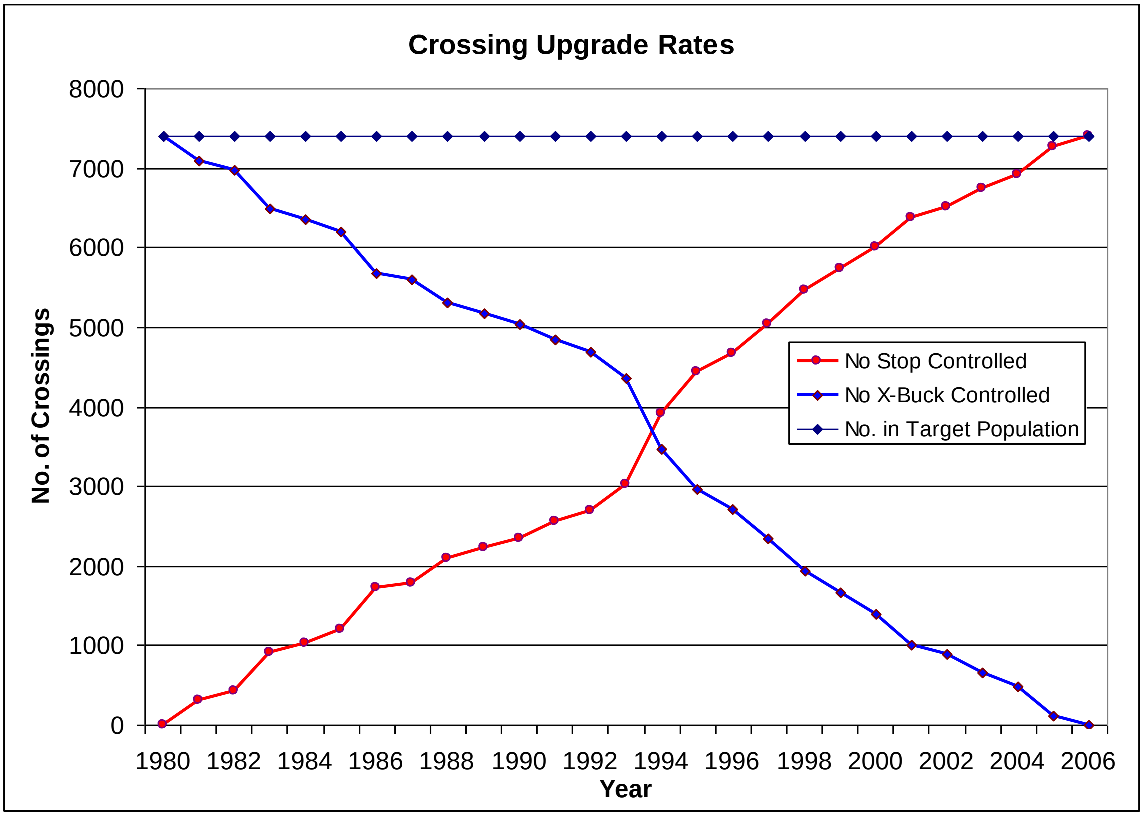


Figure 11: Accumulated number of crossing types annually by crossing type

At each crossing, accident frequencies were compiled and distributions prepared by year of accident. In this compilation, the accidents that occurred during the time that a crossing was controlled by crossbucks-only were separated from the accidents that occurred when the crossing was controlled by Stop signs. Comparing the accident frequencies before and after upgrade over the 26-year period is useful because the only discernable difference for the population is limited to the before-after sign controls. This unique set allows this research to determine differences that contributed to the impact of Stop signs.

3.1.4 Data Reduction for Accident-Propensity Comparison

A query sequence was compiled to extract records from the Grade-Crossing Inventory History database that indicated the date when crossings were updated to Stop controls and the duration during which the crossings were under each control type. The Grade-Crossing Accident History database was then queried to link accidents at each crossing that occurred in the respective phases. Frequencies of accidents were calculated for each crossing in each phase.

Appropriate independent variables were then selected from the database. A list of evaluated independent variables, their definitions, and their categorical groupings can be seen on Table 1. Variables were further categorized into subcategories found in the FRA databases. To create categorical data for this comparison analysis, continuous data were grouped into ranges. The query result was formatted for input to logistic-regression analysis.

3.1.5 Data Reduction for Accident-Prediction Model

Records were extracted from the Grade-Crossing Inventory History database for each crossing with phase duration date limits. These records were then linked to records in the Grade-Crossing Accident History database for each respective crossing. The result was formatted for input for negative-binomial regression modeling as shown on Table 2 (see Appendix 4). Variables were categorized into subcategories found in the FRA databases. Continuous data were then grouped into ranges, as in the previous analysis, to create categorical data for negative-binomial modeling.

Table 1: Descriptions of independent variables (accident characteristics) used in hypothesis testing

Variable Name	Definition	Levels
INJURIES	# of injured for reporting Railroad calculated from F6180.55a's submitted	Injury // No injury
VEHICLE SPEED	highway user estimated speed:	Speed in miles per hour
VEHICLE TYPE	highway user type of vehicle:	Car // Truck/bus // Other
POSITION	position of highway user:	Stuck // Moving over crossing
VISIBILITY (TIME OF DAY)	daylight period	Day // Dawn/dusk // Night
WEATHER	weather conditions:	Good // Cloudy // Severe
TRACK CLASSIFICATION	FRA track class: 1-6	Lower track classes (1 2 3) = 0 Higher track classes (4 5 6) =1
TRAIN SPEED	speed of train in miles per hour	<=30 mph // >30 mph
WARNING	location of warning:	Both sides

LOCATION		Side of vehicle approach Opposite side of vehicle approach
LIGHTS	lights at crossing:	yes // no
MOTORIST ACTION	action of motorist:	Stopped and then proceeded (STP) Stopped on crossing (SOC) Did not stop (DNS)
SIGHT DISTANCE	primary obstruction of track view:	Not obstructed // Obstructed
DRIVER	highway vehicle driver casualty	Driver casualty // Driver not casualty
USERS KILLED	# of highway-rail crossing users killed	User killed // User not killed

Table 2: Data input type used for negative-binomial regression

CROSSING ID	NUMBER OF ACCIDENTS	CONTROL PERIOD (YRS)	CONTROL TREATMENT (X1) [STOP(1) OR X-BUCK(0)]	OTHER CROSSING FEATURES
	λ_i	N	X1	X2,…….Xi
00001	2	16	0	---
00001	5	10	1	---
00002	3	5	0	---
00002	7	21	1	---
---	---	---	---	---

During the analysis it was recognized that distributions of paved and unpaved roads could cause problems in the results, since AADT was substantially different for each type of road surface. This problem was resolved by querying the data to create separate input sets for paved and unpaved roads. Then these datasets were prepared separate for negative-binomial regression.

3.2 Research Methodology

3.2.1 Statistical Analysis of Overall Accident Experience

Sites were selected for before- and after-upgrade assessment. Crossing subsets that had posting configuration changes were identified:

1. Timeframes in which they were Crossbucks-only controlled
2. Timeframes in which they were Stop-controlled

Descriptive statistics were compiled for the attributes of the identified crossings as well as for the reference dataset.

Control periods were established for each crossing to define the duration of control by Crossbucks, the year the crossing was upgraded, and the duration of control by Stop sign. For each year, beginning with the first posting change date in 1980 and continuing year to year for the balance of the study period to 2006, all crossings that had changes during each year and the number of crashes that occurred were tabulated.

Accidents were linked to the crossings by Crossing ID compiled in Crossbuck-only and Stop-control regimes. Accident frequency was computed for each year for the crossings, noting type of control. Annual accident frequencies were computed by summing the yearly number of accidents occurring at Crossbucks and dividing by the number of Crossbuck- controlled crossings that existed that year. The same was done for Stop-controlled crossings.

$$\overline{K}_y = 1000\left(\frac{\sum K_{iy}}{n_y}\right) \qquad \text{(Eq. 1)}$$

Where:

$\overline{K}_y$ = Average accident frequency (per 1000 crossings) in year y

K_{iy} = Number of accidents at crossing i in year y

n_y = Number of crossings existing in year y

This process yielded a tabulation of accident frequencies for both the Crossbuck-only-controlled crossings (before) and the Stop-controlled crossings (after) for each year in the study period and the difference in number of crashes in the two periods (before and after). Analysis was made of accident frequency before and after Stop-control was installed at target crossings. The results were tabulated by accidents per 1000 crossings per year and plotted for each year for each control type.

A statistical analysis was made of the results to determine if the difference between the two control group accident frequencies was significant. A test was made to determine the distribution of the datasets and to test their differences. The null hypothesis for this study was that there is no difference in accident frequencies at highway-railroad grade crossings controlled by Crossbucks-only and those controlled by Stop signs.

3.2.2 Accident Propensity Comparison

The difference between accident frequencies under the two passive controls over the study period was determined in part one of the research. In part two, a comparison was made of accident propensity for the subject passive controls, defining parameters associated with the crossings and subsequent accidents, in order to explain the difference in the accident frequencies defined in the first part of the research.

Categories of the parameters found in the FRA databases were compared to a common base state to evaluate accident propensity for the various attributes. For example, accidents that occurred at dawn/dusk and accidents that occurred at night were each compared to a base state of accidents occurring in daylight for respective Stop and Crossbuck-only configurations. In this way, the propensities for accidents were established for Stop and Crossbuck-only configurations according to the parameters found in the FRA databases, relative to each other.

The analysis needed to evaluate dichotomous data – two conditions at a time – for two periods of configuration. Since there are issues with ordinary linear regression, logit or probit regression is normally used.(37) The logit regression model was used for this research.

Logistic regression is one of a class of models known as generalized linear models. It belongs to the group of regression methods used to describe the relationship between explanatory variables and a discrete response variable. Binary-logistic regression can be used to test association between a dependent variable and related potential factors, to rank the relative importance of independent variables, and to assess interaction effects.(37) It is proper to use when the dependent is a dichotomous variable (did or didn't happen). Binary-logistic regression is used in this study because the dependent variable Y (sign treatment) can take on two values Y = 0 (before, when treatment was Crossbuck-only) or Y = 1 (after, when the treatment had changed by the addition of Stop signs).

Target crossings were isolated from the Grade-Crossing Inventory History database. Associated accident records were then extracted from the Grade-Crossing Accident History database and prepared for logistic-regression analysis.

In logistic regression, the dependent variable is a called a “logit”. A logit model was used to compare the propensity of motorists to experience crashes at the two types of passive railroad grade-crossing treatments. The logit is expressed as the natural logarithm of the odds as shown in Equation 2.

$$Logit\ (P) = \ln\ (odds) = \ln\left(\frac{P}{1-P}\right) \qquad \text{(Eq. 2)}$$

$$\mathrm{g}(x) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \qquad \text{(Eq. 3)}$$

Where:

P = Probability of an event occurring

$1-P$ = Probability of an event not occurring

$\mathrm{g}(x)$ = A measure of the total contribution of all risk factors used in the model

$X_{1\ldots n}$ = Independent variables of interest

β_n = Model coefficients

From Equation 2, P represents the probability of an accident occurring for a given set of risk factors. If we let $\mathrm{g}(x)$, represent exposure to that set of accident risk factors as demonstrated in Equation 4, we can build the logistic regression model. The function $g(x)$ is set equal to the logit.

$$Logit(P) = \ln\left[\frac{P}{1-P}\right] = g(x) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n \qquad \text{(Eq. 4)}$$

$$\ln\left[\frac{P}{1-P}\right] = g(x) \qquad \text{(Eq. 5)}$$

Reducing Equation 5, the logit of the multiple logistic-regression model (link function), takes the form shown in Equation 6 and is used to model how the probability P of an event may be affected by one or more explanatory variables.

$$\left(\frac{P}{1-P}\right) = e^{g(x)}$$

$$P = \frac{e^{g(x)}}{1+e^{g(x)}} \qquad \text{(Eq. 6)}$$

In this research, odds ratio represents relative risk comparison between Stop-controlled and Crossbuck-only crossings. The odds ratio tells the relative amount by which the odds of the outcome increase or decrease when the value of the predictor value is increased by one unit. In the comparisons between accidents occurring at Stop signs and accidents occurring at Crossbucks-only:

1. An odds ratio of 1 signifies there is no difference in risk between the two comparison categories.
2. An odds ratio of <1 signifies accidents in the comparison categories are less likely to occur at crossings treated with Stop signs than at crossings treated with Crossbucks-only.

3. An odds ratio of >1 signifies accidents are more likely to occur at crossings treated with Stop signs than at crossings treated with Crossbucks-only.

3.2.3 Statistical Modeling of Accident Frequency

The objective of this part of the research is to develop statistical accident-frequency models to be used for accident prediction in the target population in order to evaluate safety performance of stop-controlled crossing attributes and to identify significant accident risk factors that reflect crossing-related attributes. The models are developed from the number of accidents, expressed as count data, which occurred at each crossing during respective sign-control periods. It was found in a previous study (43) that using Poisson models to predict accident frequency at grade crossings results in concerns about overdispersion. This problem can be overcome by using more flexible negative-binomial models. Therefore, the negative-binomial model was applied in this study.

The negative-binomial regression model introduces an error compensation term, ε_i, to account for the bias caused by overdispersion, as shown in Equation 7.

$$\ln(\lambda_i) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_i X_i + \varepsilon_i \qquad \text{(Eq. 7)}$$

Where:

β_0 = Intercept

X_i = Independent variables of interest

β_i = Model coefficients for independent variable X_i

λ_i = Expected number of collisions

Introducing this error term into the formulation of the NB model allows the variance to be different from the mean in such a way as shown in Equation 8.

$$Var(k_i) = E(k_i)[1 + \alpha E(k_i)] \qquad \text{(Eq. 8)}$$

Where:

$E(k_i)$ = Expected value of accident counts at crossing i

$\acute{\alpha}$ = Measure of dispersion, equal to the variance of the error term (gamma distributed rather than normally distributed as in the case of the Poisson model)

The difference and dynamic of the NB model rest with the measure of dispersion $\acute{\alpha}$. It should be noted that as $\acute{\alpha} \rightarrow 0$, Var$(k_i) \rightarrow E(k_i)$, converging to a Poisson model. In this study, by assuming the negative-binomial model and observing the dispersion term, $\acute{\alpha}$, the null hypothesis of equi-dispersion was tested. The negative binomial distribution has the form shown in Equation 9.

$$P(k_i) = \frac{\Gamma(1/\alpha) + k_i)}{\Gamma(1/\alpha) k_i!} \left(\frac{(1/\alpha)}{(1/\alpha) + k_i!}\right)^{1/\alpha} \left(\frac{(k_i)}{(1/\alpha) + k_i!}\right)^{k_i} \qquad \text{(Eq. 9)}$$

Since the duration of the control period for Crossbucks-only or Stop signs was different at each crossing, this duration of the control period was selected as an offset variable (N) in the negative-binomial model. Thus, the negative-binomial model is used to estimate the accident rate at each crossing per year ($\mu = \lambda_i / N$) when a crossing is controlled by either Crossbucks-only or Stop signs. Although the control pattern was treated as an independent factor, other independent variables of crossing characteristics were also recorded in the Grade-Crossing Inventory database. Table 2 illustrates the data input format for the negative-binomial regression model. The expected accident rate at each crossing per year depends on the explanatory variables and can be expressed exponentially as Equation 10.

$$\mu = \lambda_i / N = \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_i X_i) \quad \text{(Eq. 10)}$$

The SAS program procedure, GENMOD, was used for model development. Hypothesis testing was based on a significance level of 0.05.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Statistical Analysis of Overall Accident Experience

In1980 at the beginning of the study period, all crossings in the target population were controlled by Crossbucks only. Each was upgraded to Stop control at some time in the ensuing 26-year analysis period. On average during that period, approximately 232 crashes occurred annually at the 7,394 population crossing sites. An annual average of 137 crashes occurred at Crossbuck-controlled crossings and 95 at Stop-controlled crossings. Descriptive statistics compiled for the two control categories are reflected in Table 3.

Table 4 shows results of the Kolmogorov-Smirnov normality test for the accident distributions of the two study groups. It was found that accident frequencies were normally distributed at both Crossbuck- and Stop-controlled crossings at a significance level of $p>0.05$ ($p= 0.934$ for Stop signs and $p= 0.071$ for Crossbucks). Histograms and curves of accident frequencies plotted on Figure 12 represent the two normal distributions. ANOVA results show that there is a statistically significant difference (F1, 51, 21.726, $p< 0.001$) between accident frequencies for target crossings during Crossbuck- and Stop-control phases.

Results indicate a mean of 27.131 crashes per 1,000 crossings per year at Stop-controlled crossings and a mean of 39.869 crashes per 1,000 crossings per year for Crossbucks-controlled crossings. This is a difference of 12.738

Table 3: Descriptive statistics for accident distributions

					95% Confidence Interval for Mean			
	N	Mean	Std. Dev.	Std. Error	Lower Upper	Bound Bound	Min. Lower Bound	Max. Upper Bound
Stop	26	27.131	5.4108	1.0611	24.945	29.316	17.4	37.5
X-buck	26	39.869	12.8419	2.5185	34.682	45.056	23.6	96.8
Total	52	33.500	11.6857	1.6205	30.247	36.753	17.4	96.8

Table 4: One-sample Kolmogorov-Smirnov test for normality

	Parameters	Stop	Crossbuck
	N	26	26
Normal Parameters	Mean	27.131	39.869
	Std. Deviation	5.4108	12.8419
Most Extreme Differences	Absolute	.106	.254
	Positive	.068	.254
	Negative	-.106	-.206
	Kolmogorov-Smirnov Z	.539	1.293
	Asymp. Sig. (2-tailed)	.934	.071

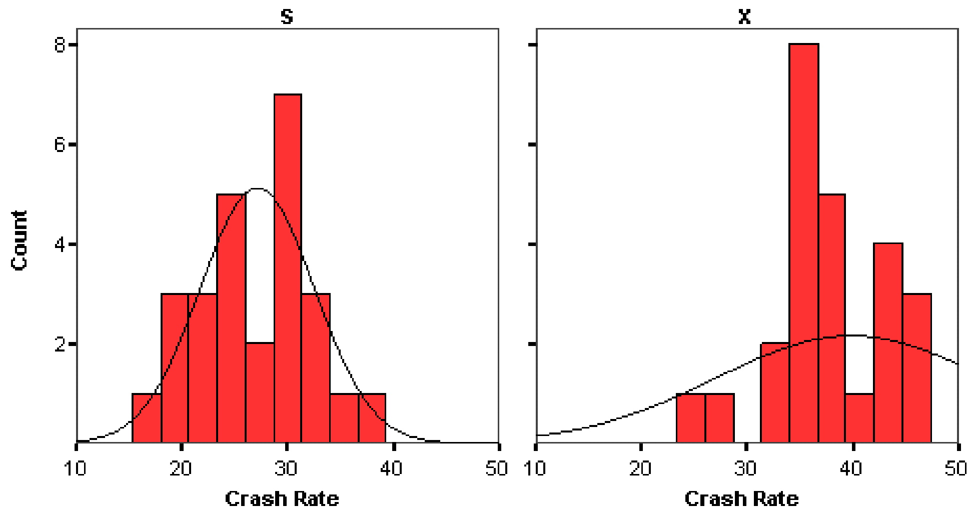


Figure 12: Histogram of crash frequencies of Stop-controlled (S) and Crossbuck-controlled (X) grade-crossings

crashes/1000 crossings/year, or a 46.95% higher accident frequency at Crossbucks than at Stop signs.

At the beginning of the study period, all crossings in the target population were controlled by Crossbucks-only. Over the next 26 years, they were gradually converted to Stop control. By the end of the study period all target crossings had been upgraded to Stop control. The conversions proceeded continuously; therefore, evenly distributed groupings of crossings with different before and after period durations evolved.

Accident frequencies for target crossings per 1,000 crossings were plotted and are shown on Figure 13. Also shown are crossings that were never upgraded to Stop control. It is apparent that the target crossings had a higher

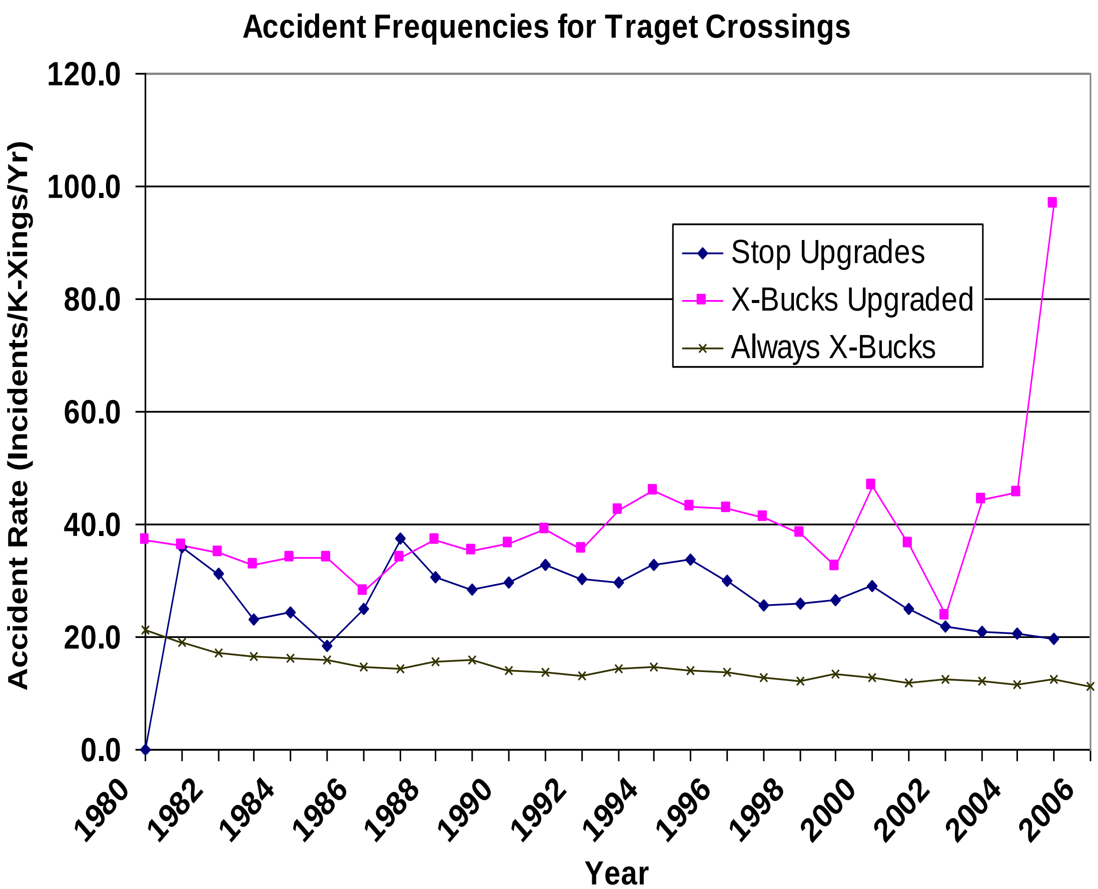


Figure 13: Accident frequencies at crossings upgraded from Crossbuck to Stop control in before-after analysis

accident frequency than the non-upgraded crossings. Crossings that were always Crossbucks had fewer crashes in general. On the other hand, it is reasonable to assume that the purpose for upgrading the target crossings to Stop signs was because the danger was perceived higher at those crossings or an accident had occurred. Also, some states and local railroad jurisdictions chose to upgrade entire groups of their inventory to Stop-sign control.

Figure 13 shows that consistently lower accident frequencies were found during the Stop-sign phase of the study period than during the Crossbucks-only phase. One is also aware of the sizeable fluctuations for opposite controls on each end of the graph. These fluctuations result from low numbers of crossings in one of the two control types during the beginning or end of the study period. It is also noted that Crossbuck accident frequencies remained fairly constant in magnitude over the period, while Stop-controlled crossing accident frequencies decreased, particularly after 1990, tending toward the lower bound of the range as the number of Stop-sign postings increased.

Figure 14 shows the combined accident frequencies of the target population (Crossbucks-only and Stop signs) compared to crossings that were never upgraded over the the entire study period. The combined accident frequencies of the target population crossings decreased from a value equal to the Crossbuck-only accident frequency in 1980 to the lower end of the range of values for Stop-controlled crossings in 2006.

Although Raub and Lucke (36), in their study of seven Midwestern states over a 10-year period extending from 1994 to 2003 found the highest collision

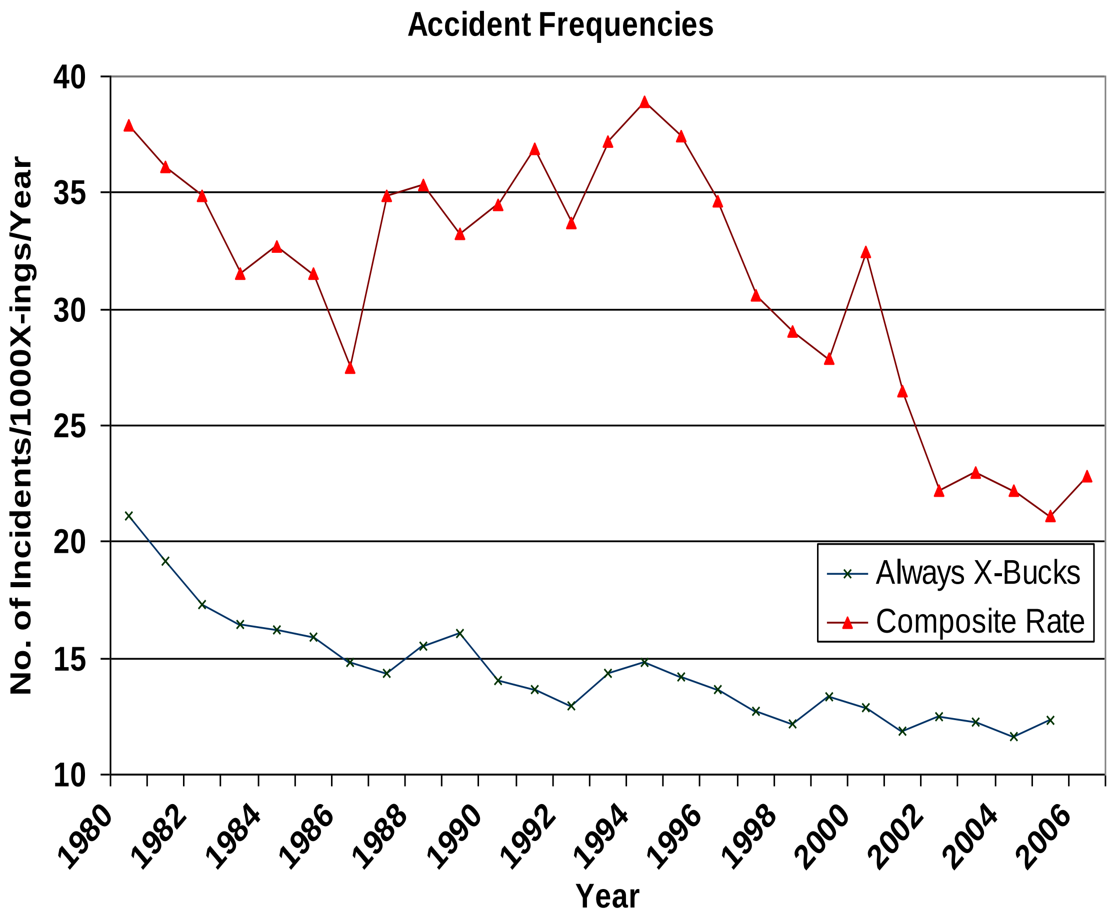


Figure 14: Mean accident frequency for entire study population compared to crossings that were always Crossbuck controlled

frequencies were at locations where the warning device was a Stop sign, Figure 14 reflects the overall decrease in accident frequencies for the population as crossings were upgraded to Stop signs. On Figure 15, general linear trends are plotted for accident frequencies at both upgraded crossings and crossings that were always Crossbucks over the entire 26-year study period. In both cases the general trend direction is downward.

Figure 16 shows a more accelerated general linear trend in accident frequencies after 1991 (ISTEA). By this time, approximately half of the study period had passed and Stop-controlled crossings were increasingly the predominant control device in the target population. The slope of the trend in this region of the curve is much steeper than for the overall period, indicating an accelerated decline in accident frequency. As the number of crossings with Stop-sign treatment increased, the accident frequency at those crossings decreased at a rate of up to 5.9 times the accident frequency at lower-risk crossings that had always been Crossbuck controlled.

4.2 Accident Propensity Comparison

4.2.1 Significant Factors Contributing to Difference in Accident Frequencies

A logistic regression was run to determine significant factors that contributed to the difference in accident frequencies established in the statistical analysis of overall accident experience. The results of the main-effect model are tabulated on Table 5 and discussed in this section. The main-effect model

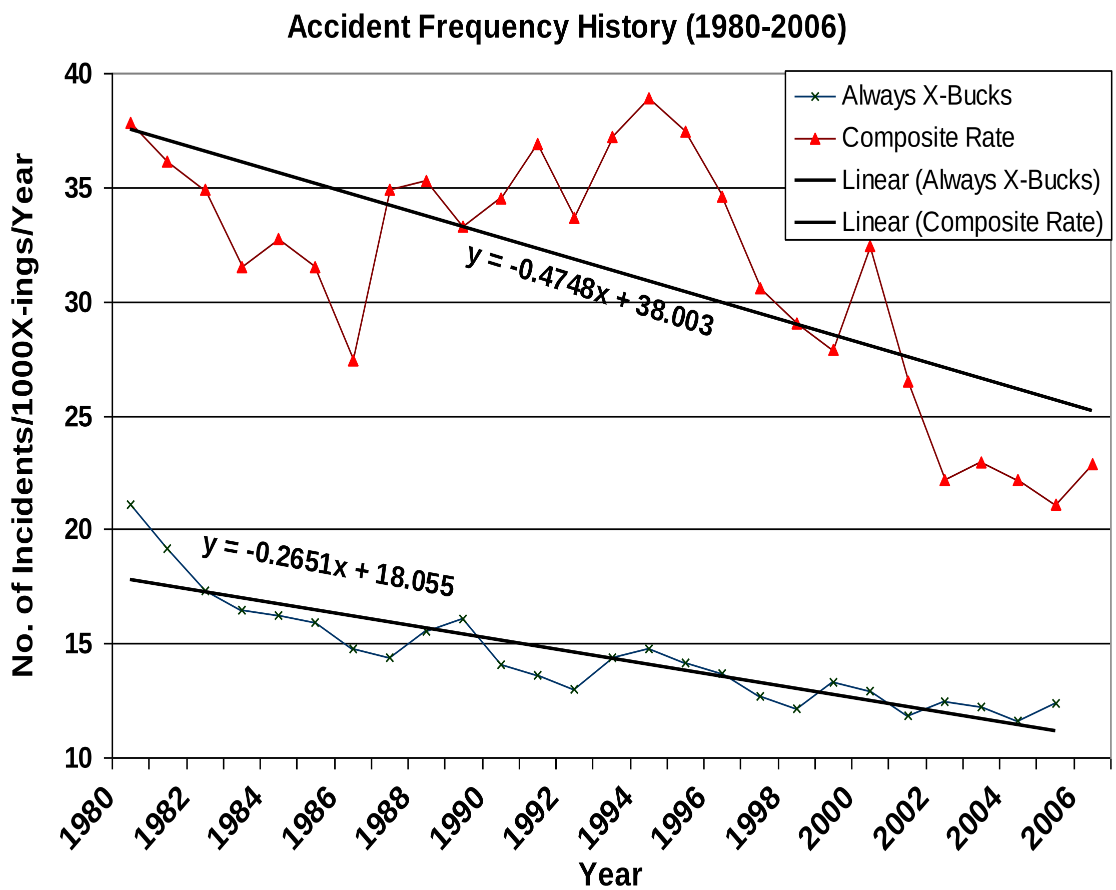


Figure 15: General linear trend in accident frequencies at upgraded crossings compared to crossings that were always Crossbucks

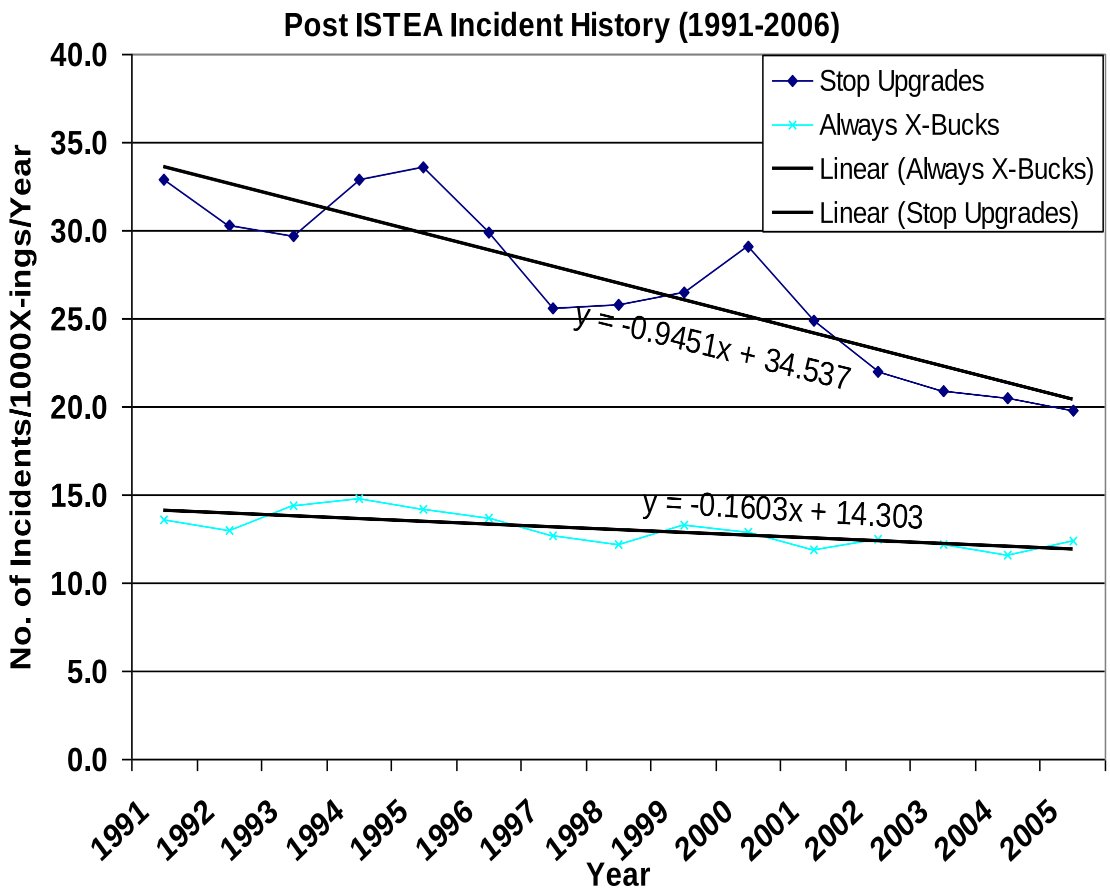


Figure 16: General linear trend in post-ISTEA accident frequencies at upgraded crossings compared to crossings that were always Crossbucks

Table 5: Main-effect model

Parameter	Estimate	Odds Ratio	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	0.2366		0.1164	4.1299	0.0421
AADT				8.3213	0.0156
>1000 vs. <=500	-0.1516	0.859	0.0827	3.3619	0.0667
500-1000 vs. <=500	-0.2046	0.815	0.0813	6.3325	0.0119
ADVANCED WARNING				8.5981	0.0034
Yes vs. No	-0.1707	0.843	0.0582	8.5981	0.0034
VEHICLE TYPE				13.9546	0.0009
Other vs. Car	-0.00953	0.991	0.1352	0.005	0.9438
Truck/Bus vs. Car	-0.2196	0.803	0.0593	13.6952	0.0002
VISIBLTY (TIME OF DAY)				30.0440	<.0001
Night vs. Daytime	-0.3402	0.712	0.063	29.1799	<.0001
Dawn/Dusk vs. Daytime	-0.1983	0.820	0.1104	3.225	0.0725
MOTORIST ACTION				33.5221	<.0001
S.O.C. vs. S.T.P.	-0.4996	0.607	0.1081	21.368	<.0001
D.N.S. vs. S.T.P.	-0.5777	0.561	0.0998	33.4757	<.0001
SIGHT DISTANCE				28.0590	<.0001
Obstructed vs. Not Obstructed	-0.625	0.535	0.118	28.059	<.0001
INJURIES				5.0618	0.0245
Injuries vs. None	-0.1326	0.876	0.0589	5.0618	0.0245
TRACK CLASSIFICATION				11.4958	0.0007
Higher vs. Lower	0.2086	1.232	0.0615	11.4958	0.0007
TRAIN SPEED				29.6558	<.0001
>30 mph vs. <=30 mph	0.3479	1.416	0.0639	29.6558	<.0001

estimate in the logistic-regression analysis identified nine factors that were significantly associated with accident risk change at highway-railroad grade crossings after Stop-sign treatment: AADT, advanced warning, vehicle type, time of day visibility, motorist action at the crossing, view of the tracks, injuries, track classification, and train speed. All nine factors were significant at the $p<0.01$ level except for injuries, which were significant at $p=0.02$.

Parameter categories and specific comparisons between subcategories for the significant factors can also be seen in Table 5. Subcategory comparisons explain expected change in model results with variation within the parameter category relative to a base subcategory. The sign on the estimate indicates the slope of the model as influenced by the subcategory. The Odds Ratio compares the expected results in one subcategory to another.

The odds ratio gives a measure of the propensity, or natural inclination, found in the data, such as the inclination for the odds of an accident to increase or decrease as AADT increases or decreases. Odds ratio is a measure of relative risk compared to a base state, such as ≤ 500 vehicles per day for AADT. For a discussion of odds and odds ratio, see Appendix 3.

Examination of odds ratios for AADT subcategories indicates that, compared to Crossbucks-only, the propensity of an accident occurring at a Stop-controlled crossing with 500-1,000 vehicles per day AADT is 18.5 percent less ($p= 0.0119$) than when the AADT is less than or equal to 500 vehicles per day. Accident propensity is 14 percent less when the AADT is greater than 1,000 vehicles per day ($p= 0.0667$). However, the inventory data indicate that most passive crossings in the target population have less than 500 vehicles per day. The decreased propensity could be a result of the decreasing numbers of crossings with AADT greater than 500 vehicles per day.

Stop-controlled crossings with posted advanced-warning signs showed a 15.7 percent decrease in the likelihood of accidents over crossings without advanced-warning signs ($p=0.0034$). It is reasonable to expect a decrease in accident propensity with advanced warning.

Two comparisons were made in the category of Vehicle Type. The first compared accident propensity for trucks/buses to passenger cars and the second compared the accident propensity for other vehicles to passenger cars. At Stop-controlled crossings, the odds ratio for trucks/buses reflects an accident propensity 20 percent less with passenger cars ($p=0.0002$). For other types of vehicles there is essentially no difference in accident propensity with passenger cars. The odds ratio was 0.99, not significant statistically ($p=0.9438$).

The Visibility (time of day) category describes the propensity for accidents under different natural lighting conditions and traffic characteristic for those times of day. In the Visibility category, the odds of an accident occurring was compared for nighttime and dawn/dusk hours. Both subcategory comparisons reflected that Stop signs had a benefit during these diminished visibility conditions. Accident propensity during dawn/dusk hours reflected an 18 percent less likelihood of crash than during daytime, but was only marginally significant at $p= 0.0725$. During nighttime hours, accident propensity was 29 percent less than daytime hours, and was significant at $p< 0.0001$. This seems reasonable as view of approaching trains is a greater problem during periods with no lighting. It should be noted that no data was available regarding exposure during these periods. The comparison was made as if the exposure were the same as that experienced during daytime hours.

In the category of Motorist Action, the odds were compared for two unsafe conditions, motorist-stopped-on-crossing (SOC) and those who reportedly did not stop (DNS). The two categories were compared to the odds of an accident for motorists who were reported to have stopped and then proceeded (STP). The propensity for SOC crashes was 39 percent less at Stop controls, at a statistical significance of $p<0.0001$. The propensity for DNS crashes was 44 percent less, again at a significance of $p<0.0001$.

Stop signs require a motorist to stop at crossings, regardless of sight-distance visibility. However, Stop signs are not always posted when sight distance is obstructed. The category of crossing Sight Distance included subcategories of obstructed and unobstructed sight distance. The obstruction could be from vegetation, buildings, topography or other interference with direct view of the tracks.

Stop signs helped when obstructions were present; crash propensity was 46.5 percent less for obstructed sight distances compared to unobstructed ($p<0.0001$). It is plausible that when motorists cannot see the tracks and are totally dependent on the Stop sign, they show greater respect for the potentially dangerous condition.

Using non-injury accidents as a baseline reference for the Injuries category, injury accident propensity was 12.4 percent less at Stop-sign-controlled crossings ($p=0.0245$). This is an important finding. The indication is that injury accidents or severe accidents are more likely to be experienced at Crossbuck-only crossings rather than Stop controlled crossings.

Track classifications correspond to train speeds (See Appendix 2) and were grouped into two categories: lower (classes 1, 2, 3) and higher (classes 4, 5, 6). Lower track classifications require lower train speeds. As was expected, in both categories accident propensity increased with higher train speed/track classification. Both categories were statistically significant ($p< 0.001$).

4.2.2 Interaction Effects between Factors Contributing to Accident Frequency Differences

After confirming the main-effect model, a second logistic-regression analysis explored the possible significant interactions between factors and identified several variables that reflected a significant interactive association concerning accident frequencies (Table 6).

Four interaction effects of significance were identified between:

1. Visibility (time of day) and sight distance (obstruction) ($p =0.0031$)
2. Injury accidents and track classification ($p = 0.0309$)
3. Injury accidents and train speed ($p =0.0161$)
4. Advanced-warning signage and vehicle type ($p = 0.0408$)

Interactions 2 and 3 are equivalent as noted in section 4.2.1.

Table 6: Interaction-effect model

Parameter	Estimate	Odds Ratio	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	0.3354		0.1221	7.5433	0.006
AADT				8.8736	0.0118
>1000 vs. <=500	-0.1652	0.848	0.0829	3.9689	0.0463
500-1000 vs. <=500	-0.2065	0.813	0.0815	6.4179	0.0113
ADVANCED WARNING				14.5861	0.0001
Yes vs No	-0.2822	0.754	0.0739	14.5861	0.0001
VEHICLE TYPE				16.3846	0.0003
Other vs. Car	-0.2729	0.761	0.2327	1.3756	0.2408
Truck/Bus vs. Car	-0.418	0.658	0.1041	16.1117	<.0001
VISIBLTY (TIME OF DAY)				36.523	<.0001
Night vs. Daytime	-0.3796	0.684	0.0643	34.8105	<.0001
Dawn/Dusk vs. Daytime	-0.2584	0.772	0.1144	5.1017	0.0239
MOTORIST ACTION				32.4299	<.0001
S.O.C. vs. S.T.P.	-0.4953	0.609	0.1085	20.8364	<.0001
D.N.S. vs. S.T.P.	-0.5703	0.565	0.1002	32.3956	<.0001
SIGHT DISTANCE				37.5891	<.0001
Obstructed vs. Not Obstructed	-0.8459	0.429	0.138	37.5891	<.0001
INJURIES				3.349	0.0672
Injuries vs. None	-0.1833	0.833	0.1002	3.349	0.0672
TRACK CLASSIFICATION				16.6894	<.0001
Higher vs. Lower	0.3068	1.359	0.0751	16.6894	<.0001
TRAIN SPEED				9.9295	0.0016
>30 mph vs. <=30 mph	0.2413	1.273	0.0766	9.9295	0.0016
VISIBILITY & SIGHT DISTANCE				11.5799	0.0031
Night & Obstructed Sight Dist.	-0.1308	0.8774	0.3085	8.099	0.0044
Dawn/Dusk & Obstructed Sight Dist.	-0.3475	0.7065	0.432	5.0789	0.0242
INJURIES & TRACK CLASS				4.6587	0.0309
Injuries & Higher Track Classes	-0.16	0.8521	0.1313	4.6587	0.0309
INJURIES & TRAIN SPEED				5.7909	0.0161
Injuries & Train Speeds > 30 mph	0.3842	1.4684	0.1356	5.7909	0.0161
ADVANCED WARNING & VEHICLE				6.3987	0.0408
Advanced Warning & Other Vehicles	-0.1427	0.867	0.2854	2.0886	0.1484
Advanced Warning & Trucks/Buses	-0.4162	0.6595	0.1251	5.1575	0.0231

The interaction results are illustrated graphically on Figures 17 through 20. The baseline interaction factor odds ratio is a comparison to itself and represents a relative risk equal to one. All other subcategories are compared to the baseline interaction factor and represent the relative risk or propensity with respect to the baseline odds ratio. When Stop signs are posted rather than Crossbucks-only, a relative risk less than one indicates that accident propensity is less than the odds of an accident occurring in the reference subcategory. A relative risk greater than one indicates that the accident propensity is higher than the odds of an accident occurring in the reference subcategory when Stop signs are posted.

Interaction between visibility (time of day) and sight distance (obstruction), is displayed on Figure 17. In all natural lighting conditions for both obstructed and unobstructed sight distance, the model reveals that Stop-controlled crossings were enhanced. All subcategories had an accident propensity less than the odds of an accident occurring in daylight visibility where sight distance was not obstructed. This is an important finding inasmuch as Stop signs were found to perform better than Crossbucks-only, on average, in the target population, reflecting the findings in the statistical analysis of overall accident experience.

Figure 18 indicates the relative risk of interactions between injury accidents at lower and higher track classifications. The model reveals a lower relative risk of injury accident occurring at all track classifications. However, the relative risk of having a non-injury accident was found to be higher at higher track classifications.

Interaction between injuries and train speed is displayed on Figure 19. The figure indicates accident propensity was less for injury accidents when train speeds were less than or equal to 30 mph. When train speeds were greater than 30 mph, the propensity for accidents increased and had a higher relative risk than crossings with non-injury accidents and train speeds less than 30 mph. This finding reinforces the finding in the previous regression analysis that injury accidents or severe accidents are more likely to be experienced at Crossbuck-only crossings, and, more specifically, when train speeds are greater than 30 mph.

Figure 20 shows interaction between advanced warning and vehicle type. It compares accident propensity for subcategories of the Vehicle Type parameter category with and without advanced warning signs posted. Figure 20 reveals that all cases have a lower risk, relative to passenger vehicles at crossings with no advanced warning signs posted.

4.3 Statistical Modeling of Accident Frequency

During analysis of the output, it was found that there is a difference in AADT distribution for paved and unpaved roads at grade crossings in the target population. Higher AADT is more likely at paved grade crossings. As reflected on Figure 21, most unpaved-crossing accidents occur when AADT is less than 100 vehicles per day; most paved-crossing accidents occur when AADT is less than 300 vehicles per day. Likewise, Eck and Shanmugam’s study (7) reported that low-volume-road grade-crossing characteristics are significantly different

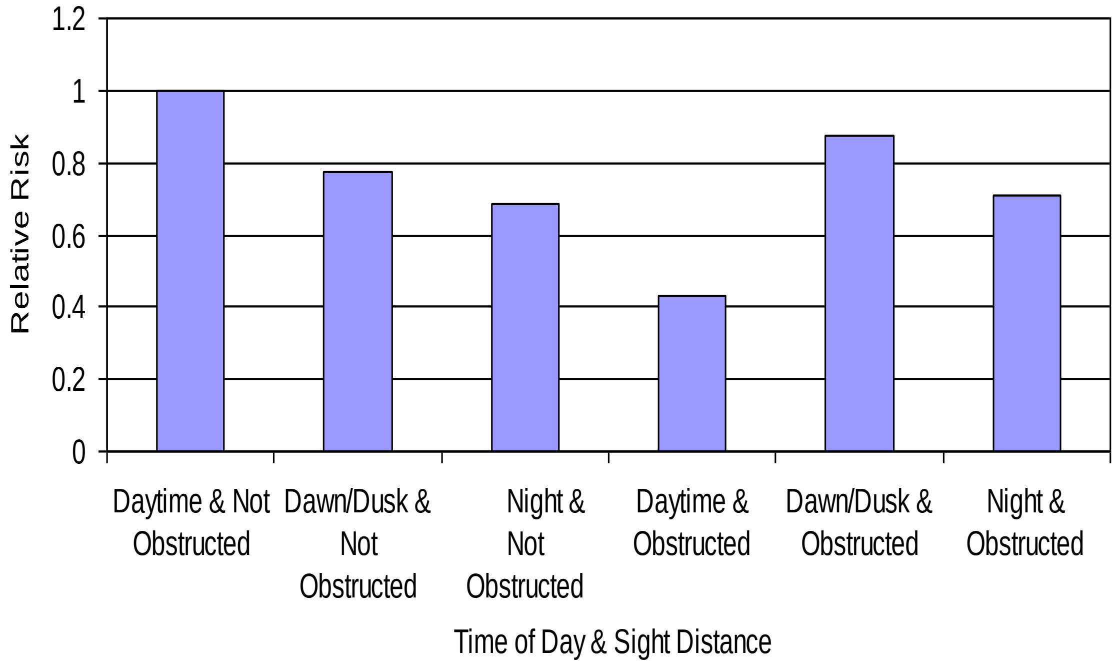


Figure 17: Interaction between time of day (visibility) and sight distance (obstruction)

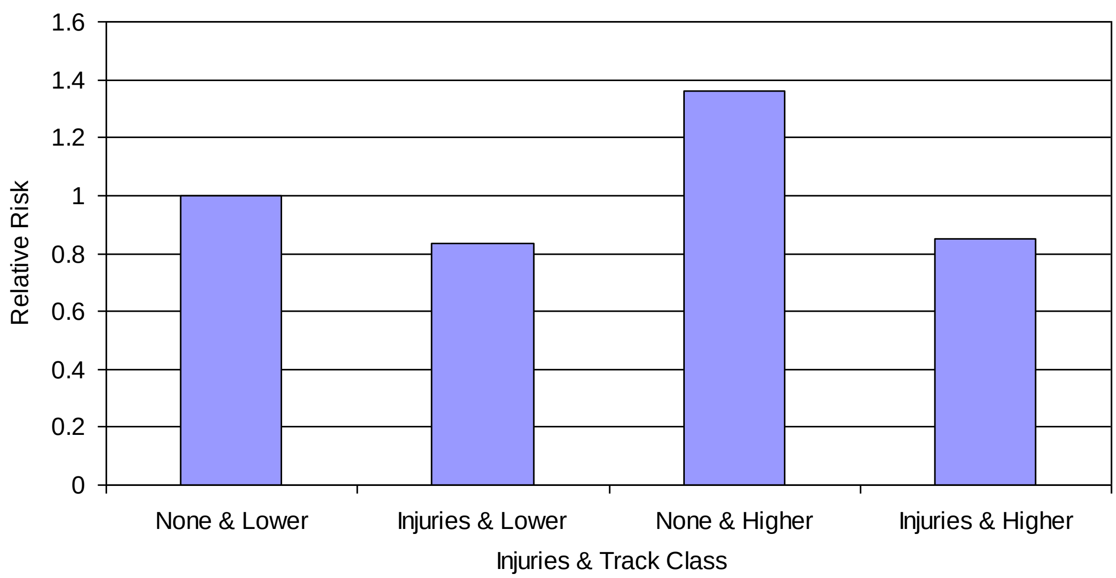


Figure 18: Interaction between injury accidents and track classification

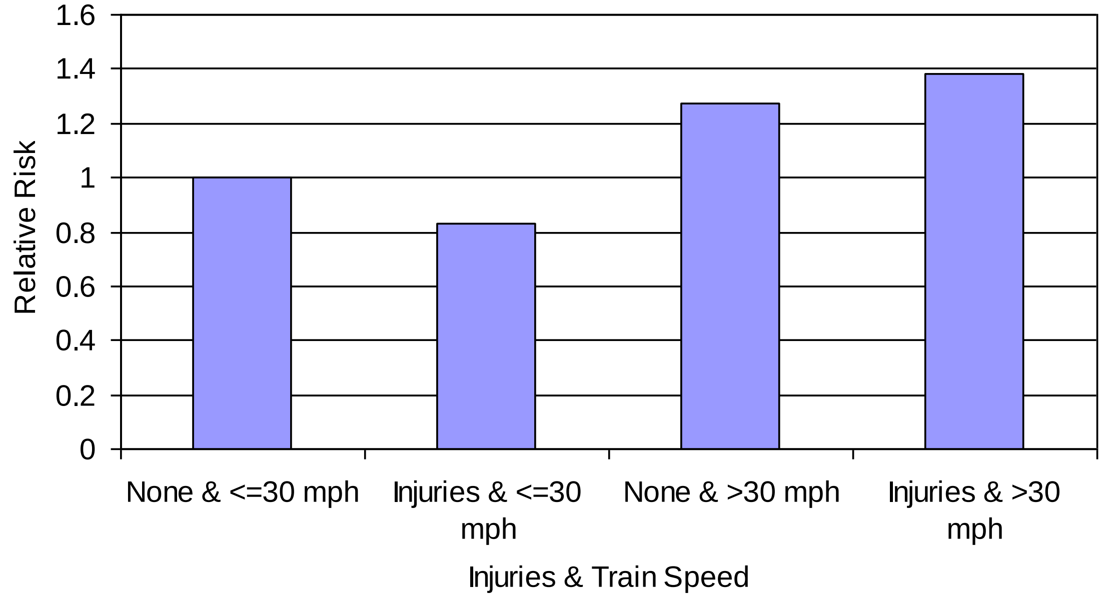


Figure 19: Interaction between injury accidents and train speed

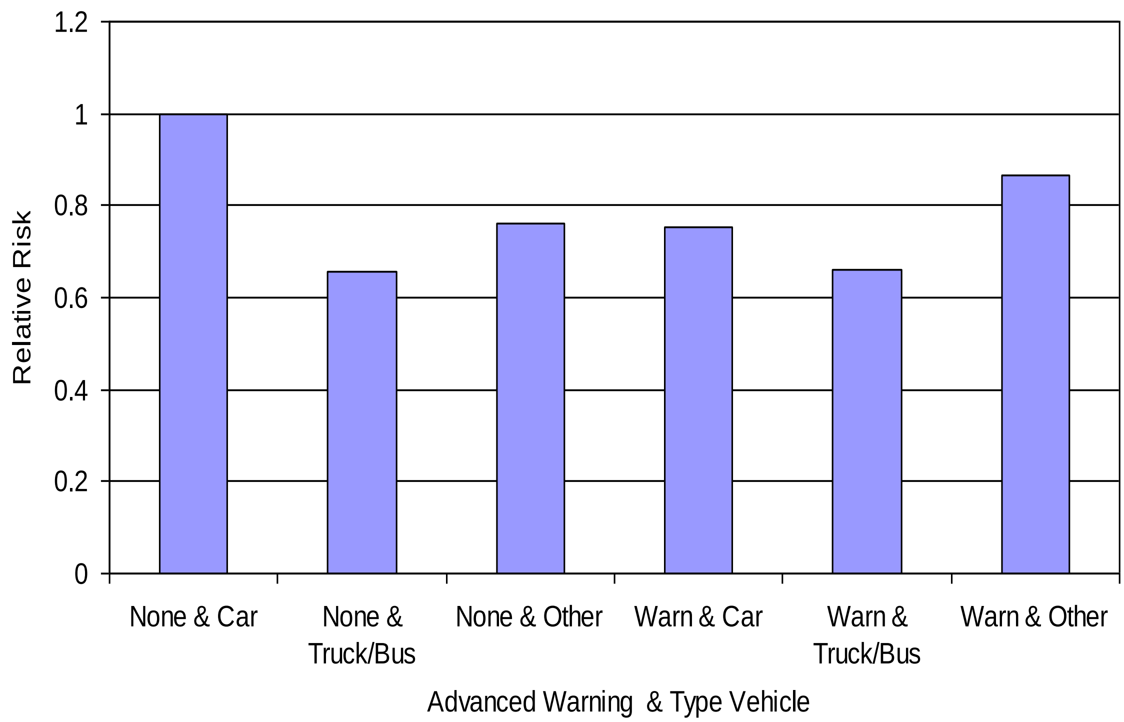


Figure 20: Interaction between advanced-warning signage and vehicle type

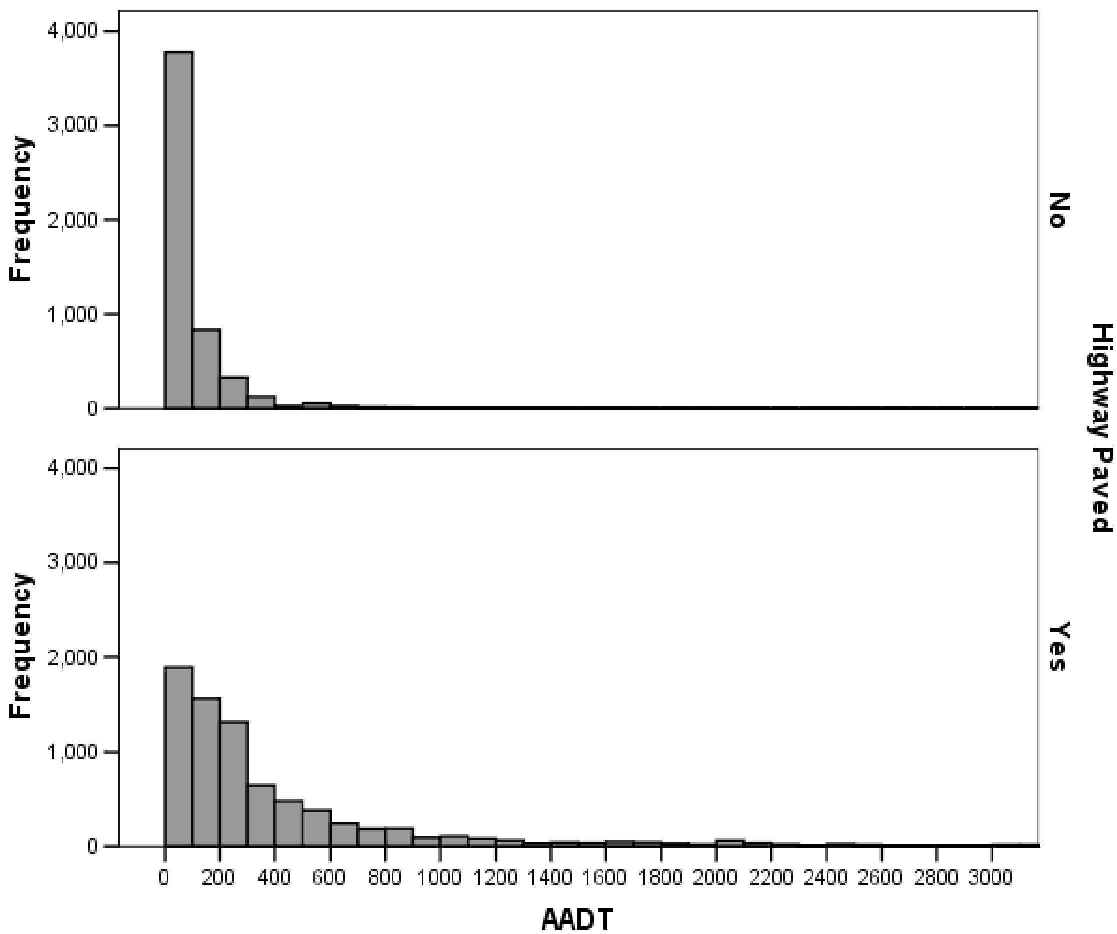


Figure 21: Frequency of crashes on paved and unpaved roads by AADT

from those of higher-volume-road grade crossings. Their study indicated that sign impact on high-volume versus low-volume roads was more evident for physical characteristics than for operational characteristics. Therefore two separate models are appropriate.

In this study, negative-binomial models were developed separately for paved and unpaved crossings in order to avoid a collinearity problem (44) between crash frequency and certain independent factors described by Eck and Shanmugam.(7)

Table 7 presents the significance tests of model parameters for both paved and unpaved crossings. For the paved-crossing model, it is found that control treatment, percent trucks, AADT, number of crossing tracks, development type adjacent to crossing, and interaction terms between control treatment, AADT, trains per day, percent trucks, and MAXTTSPD are significantly associated with the accident rate at crossings. For the unpaved crossing model, number of crossing tracks is not a significant parameter, but number of lanes is. Furthermore, the unpaved crossing model shows fewer interaction terms than the paved model. In Table 7, the measure of dispersion, *ά,* is 25.4 for the paved model and 32.6 for the unpaved. Both dispersion measures are significantly larger than one, displaying a very strong overdispersion effect, which means that the NB regression is the appropriate model instead of the Poisson model.

Coefficient estimates of model parameters reflect how independent variables are associated with accident risk at crossings: the mean number of

Table 7: Parameter estimates of the negative-binomial regression models

Model Parameter	Paved Grade Crossing			Unpaved Grade Crossing		
	Estimate	Standard Error	p-value	Estimate	Standard Error	p-value
Intercept	-10.1719	0.5129	<.0001	-13.1098	0.8476	<.0001
Control Treatment (Stop sign vs. Crossbucks)	-5.5172	0.7072	<.0001	-4.6330	0.4778	<.0001
No. Traffic Lanes	-	-	-	1.1595	0.3169	0.0003
Percent Trucks (Continuous variable, %)	0.0491	0.0126	<.0001	-0.0491	0.0173	0.0045
AADT (Continuous variable, per 1000)	0.4075	0.0934	<.0001	3.1523	1.2665	0.0128
Trains per day (Continuous variable)	0.0200	0.0223	0.3691	-0.0327	0.0183	0.0730
No. Crossing Tracks (Continuous variable)	1.3169	0.2088	<.0001	-	-	-
MAXTTSPD (Continuous variable, mph)	-0.0200	0.0103	0.0509	0.0735	0.0118	<.0001
Development Type						
Residential	0.2206	0.2584	0.3934	-1.4561	0.4140	0.0004
Commercial	-0.2331	0.3746	0.5336	-0.3511	0.8918	0.6938
Industrial	1.2587	0.4313	0.0035	3.0052	0.7447	<.0001
Institutional	-1.7452	0.9256	0.0594	-1.6280	3.3528	0.6273
Open Space	0.0000	0.0000	-	0.0000	0.0000	-
Interactions						
Control*AADT	0.6322	0.1778	0.0004	-	-	-
Control*Trains	0.1103	0.0310	0.0004	0.1346	0.0241	<.0001
Control*Tracks	-0.5472	0.2911	0.0602	-	-	-
Control*MAXTTSPD	0.0891	0.0155	<.0001	-	-	-
Dispersion	25.4236	0.6126		32.5502	1.0876	
DF		7841			5236	
Deviance		0.7084			0.5455	
Log Likelihood		-10189.1227			-5841.5960	

expected accidents increases (if coefficient is positive) or decreases (if coefficient is negative) when the value of the independent variable increases. The effects of risk factors on crossing safety are explained for paved and unpaved crossing models, respectively, as follows.

4.3.1 Paved-Crossing Model

The coefficient of the variable Control Treatment is -5.517 for the paved model. The coefficient indicates that the average number of accidents is significantly reduced after Stop signs were installed. This result is consistent with the previous finding in the statistical analysis of overall accident experience wherein the accident rate at Crossbucks-controlled crossings is significantly higher than that at Stop-controlled crossings. However, the modeling results show that the Stop-sign effect on safety performance at paved crossings is complexly interacted with AADT, trains per day, percent trucks, and MAXTTSPD.

To better explain the interaction effects, the modeling results from Table 7 were further expressed by Equations 5 and 6 for Crossbuck-only and Stop-sign control, respectively:

For Crossbucks-only control:

$$
\begin{aligned}
\mu_X = {} & \exp\{-10.172 + 0.049\ (\text{Percent Trucks}) + 0.408\ (\text{AADT}) \\
& + 0.020\ (\text{Trains per Day}) + 1.317\ (\text{No. of Crossing Tracks}) \\
& - 0.020\ \text{MAXTTSPD} + [0.221(\text{Residential}) - 0.233(\text{Commercial}) \\
& + 1.259(\text{Industrial}) - 1.745(\text{Institutional})]\} \qquad \text{(Eq. 5)}
\end{aligned}
$$

For Stop-sign control:

$$\mu_S = \exp\{ -15.689 + 0.049\ (\text{Percent Trucks}) + 1.039\ (\text{AADT})$$

$$+ 0.130\ (\text{Trains per Day}) + 0.770\ (\text{No. of Crossing Tracks})$$

$$+ 0.069\ \text{MAXTTSPD} + [0.221(\text{Residential}) - 0.233(\text{Commercial})$$

$$+ 1.259(\text{Industrial}) - 1.745(\text{Institutional})]\} \qquad \text{(Eq. 6)}$$

In both Equations 5 and 6, the positive coefficients for AADT and Trains per Day indicate that accident frequencies at crossings increase as the number of trains per day increases and as AADT increases by 1000 vehicles per day. These findings are consistent with many previous research results in crossing-accident frequency-modeling studies.(43, 44, 48)

The coefficients of AADT and Trains per Day in Equation 6 are larger than those in Equation 5, which indicates that the increasing rate of accident risk with increments of AADT and trains per day is larger when the crossings were controlled by Stop signs compared to when they were controlled by Crossbucks only. This finding supports the previous research conclusion drawn by Eck and Shanmugam (7): Stop-sign treatment is more effective at lower-volume-road grade-crossings than at higher-volume-road grade crossings, over the range of volumes associated with passive-control crossings.

The interaction effect between control treatment and number of crossing tracks is marginally significant ($p=0.0602$). When an additional track is present at a crossing, a vehicle-train accident was $e^{1.317}$ times more likely to occur if the crossing had been controlled by Crossbucks only. A vehicle-train accident was $e^{0.770}$ times more likely to occur if the crossing had been controlled by Stop sign.

Accident frequency increases with an increase in the number of crossing tracks and is larger for Crossbucks-only-controlled crossings than for Stop-controlled crossings. This implies that Stop-sign treatment is more effective at crossings with multiple tracks.

Although maximum timetable speeds are expressed in increments, the model shows that an increase in maximum timetable speed (MAXTTSPD) of one mile per hour is expected to increase accident frequency by $e^{0.069}$ times at Stop-controlled crossings but decrease accident frequency by $e^{0.020}$ times at Crossbuck-only-controlled crossings. This interaction effect between Control Treatment and MAXTTSPD shows that higher train speeds would reduce the effectiveness of the Stop-sign treatment.

The positive sign of the coefficient for Percent Trucks indicates that as the percentage of trucks in traffic increases, there is a corresponding increase in accident frequency. There is no difference between the two treatment methods. Trucks can be 40 or more times heavier than other vehicles in the traffic stream and large trucks are generally less maneuverable, accelerate slower, and take longer to stop.(45) Due to physical and operational characteristics of these heavy trucks, they can significantly impact traffic system performance and safety. Also, many trucks are required to stop at crossings by law or operating-company policy.

Development Types were treated as a single categorical variable with five subcategories; Open Space was selected as the reference category. Compared to crossings in Open Space, the crash frequency of crossings in Industrial areas is $e^{0.069}$ times higher (p=0.0035), while crash rates for crossings at Residential (p=0.3934), Commercial (p = 0.5336), and Institutional areas (p=0.0594) are not significantly different. These results are reasonable and further support the utility of the model.

4.3.2 Unpaved-Crossing Model

The coefficient of the variable Control Treatment is -4.6330 in the unpaved model. Similar to the effect illustrated in the paved model, the accident frequency in the unpaved model is also significantly reduced after Stop signs were installed. The modeling results are further expressed in Equations 7 and 8 for Crossbucks-only control and Stop-sign control, respectively:

For Crossbucks-only control:

μ_X = exp{-13.110 + 1.160 (No. Traffic Lanes) - 0.049 (Percent Trucks)

+3.152 (AADT) - 0.033 (Trains per Day) + 0.074 MAXTTSPD

+ [-1.456(Residential) - 0.3511(Commercial) + 3.005(Industrial)

- 1.628(Institutional)]} (Eq. 7)

For Stop-sign control:

μ_S = exp{-17.742 +1.160 (No. Traffic Lanes) - 0.049 (Percent Trucks)

+ 3.152 (AADT) + 0.101 (Trains per Day) + 0.074 MAXTTSPD

+ [-1.456(Residential) - 0.3511(Commercial) + 3.005(Industrial)

- 1.628(Institutional)]} (Eq. 8)

In the unpaved model, number of Trains per Day is the only variable which has a significant interaction effect with Control Treatment. The coefficient of

Trains per Day in Equation 7 is negative (-0.033) and in Equation 8 is positive (0.101). This means that as the number of trains per day increases, crash frequency on unpaved roads increases at Stop-controlled crossings, but decreases at Crossbucks-controlled crossings. This result implies that Stop-sign treatments are less effective at crossings with higher train volumes on unpaved roads. This is consistent with the findings for the paved-crossings model at higher train volumes.

Although multiple-lane unpaved roads are not common, the specific coefficient estimate (1.1595) reported in Table 7 indicates that an increased number of unpaved lanes crossing tracks results in an increased accident frequency (0.0003). One possible explanation is, when a wide unpaved road is treated as multiple-lane roadway by drivers, vehicles stopped in order to yield to an oncoming train at the crossing may be a temporary sight obstruction for drivers in the adjacent (virtual) lane, thus leading to potential accident risk.

In the unpaved model, AADT is positively correlated with accident frequency, as in the paved model. Higher traffic volumes result in higher crash frequencies.

As shown in Table 7, on unpaved roads, it was found that accident frequency will decrease slightly if the percentage of trucks and MAXTTSPD increase. This finding seems not to be intuitive because more trucks in traffic and higher train speed are generally considered as risk factors for crossing safety. A possible explanation for the modeling results is that for the unpaved crossings with higher train speed and truck volume, engineers realize their potential risk and take protective actions to enhance crossing safety, such as clearing sight obstructions, increasing sign visibility, or applying additional warning information.

Adjacent Development Type is also associated with crash frequency at unpaved crossings. Compared to crossings in Open Space, the proximity of crossings to Industrial areas leads to a much higher number of accidents ($p<0.0001$), which is consistent with the analysis in the paved model. An interesting finding is that the proximity of unpaved crossings to Residential areas is associated with a lower number of accidents ($p=0.0004$). A presumable explanation is that most of the road users in residential areas are local drivers who are familiar with the surroundings and the crossings. Crash rates for crossings at Commercial ($p=0.6938$) and Institutional areas ($p=0.6273$) are not statistically significant.

4.3.3 Negative-Binomial Accident-Prediction Models

Two models were developed for paved highway-rail grade crossings (Equations 11 and 12) and two for unpaved highway-rail grade crossings (Equations 13 and 14) from attributes and accident records of target grade crossings upgraded from Crossbucks to Stop signs since 1980. The primary purpose for the development of the four models is to synthesize the records of Stop-sign performance over the study period in order to determine if there is a limitation on the safety performance range to be expected for Stop signs versus Crossbuck-only.

The models provide insight into the safety performance expected at the target crossings and can be used in evaluation of accident risk. A new and unique set of curves for each crossing can be generated by adjusting specific values for the variables. This set of curves can be used to evaluate the range of effectiveness for each different crossing configuration. Additionally, the models can be used by the highway-rail community to examine and manage existing crossings, assess potential crossings for upgrade, and plan and design crossings as parameter values change over time.

CHAPTER 5: CONCLUSIONS AND DISCUSSION

This research in accident safety at public highway-railroad grade crossings focused on crossings that were upgraded to Stop controls from Crossbucks-only. The analysis compared accidents and accident frequencies in the same population of crossings since 1980, during both Crossbuck- and Stop-control phases. Private and pedestrian crossings and grade-separated crossings were excluded.

5.1 Statistical Analysis of Overall Accident Experience

This study focused on a 26-year accident history of passive highway-railroad grade crossings that were originally controlled by Crossbucks-only and were later upgraded to Stop controls. The first objective of the research was to assess the effectiveness of the Stop-sign treatment on crossing safety.

Annual accident frequencies for both Crossbuck control and Stop control were calculated and compared to test the hypothesis regarding Stop-sign usage safety at grade crossings. The null hypothesis for the statistical analysis of overall accident experience was that there is no difference in accident frequencies at highway-railroad grade crossings controlled by Crossbucks-only or by Stop signs. The results indicated that the null hypothesis was false and was therefore rejected.

It was found that annual accident frequencies during the period when crossings were controlled by Stop sign were consistently lower than previously when they were controlled by Crossbucks-only. This finding supports the claim that Stop-sign treatment is an effective method for improving safety at public grade crossings. This conclusion is consistent with prior accident-rate analysis for Stop-sign usage at passive crossings.(7, 9)

5.2 Accident Propensity Comparison

The second part of the research used logistic-regression modeling to examine accident-attribute frequencies of the target population. Having established that Stop-controlled crossings showed significant improvement in the safety record over the use of Crossbucks only, the objective was to evaluate the propensity for accidents in the target population and the expected safety impact of adding Stop signs.

A logit model was used to compare the propensity of motorists to experience accidents at these two types of passive railroad-grade crossing treatments. Results of the logistic regression were reported according to the main effect of various factors and variations of those factors. An additional analysis of interaction effects was made to determine relationships between factors that had significance. The odds ratio was examined to evaluate the difference in accident propensity. The main-effect model surfaced nine significant factors. A second regression found four significant interaction factors.

5.3 Statistical Modeling of Accident Frequency

Thirdly, this study developed negative-binomial accident prediction models to evaluate accident counts for highway-rail grade-crossings that include the effect of Stop-sign treatment. During model development, data was divided into paved and unpaved crossings and a negative-binomial regression was run for both crossing types. Model results were tabulated and four accident-prediction equations were generated.

The model results corresponded to the statistical analysis of overall accident experience that Stop-sign treatment reduced accident frequency. Through evaluating the factors affecting safety at passive crossings based on the negative-binomial models, the following conclusions applicable to the study's target population can be drawn.

At paved highway-rail grade crossings:

1. Accident frequencies increase as AADT, percentage of trucks, number of trains per day, and number of tracks increase.
2. Stop-sign treatment is more effective at low-volume vehicle and train crossings.
3. Stop-sign treatment is more effective at crossings with multiple tracks.
4. Higher train speeds reduce the effectiveness of Stop-sign treatment.
5. Accident frequencies increase in proximity to industrial areas.

At unpaved highway-rail grade crossings:

1. Stop-sign treatment is less effective at higher train volumes.

2. Accident frequencies increase as AADT and the number of highway lanes increase.
3. Accident frequencies decrease in proximity to residential areas.
4. Accident frequencies increase in proximity to industrial areas.

5.4 Study Limits and Recommendations

Certain limitations of this study should be discussed. Goodness-of-fit for the models showed that deviance values are not very close to one (see Table 7), which indicates model misspecification to some extent. One possible explanation is that the FRA Grade-Crossing Inventory database may neglect various important factors associated with crossing accident risk resulting in such factors affecting the model. For example, sight distance as an important engineering factor is not recorded in the Grade-Crossing Inventory although one primary consideration for using a Stop sign is limited sight distance at a crossing (3) and restricted sight distance was identified as a significant risk factor in previous crossing studies.(43, 44) Another possible explanation is that the model fitting was based on crossings across the entire United States and, therefore, crossing design attributes, environmental features, and driver characteristics are not as homogenous as those in local crossing databases, thus leading to a larger variation of accident frequency.

The results of this research are significant, but they do not indicate that all passive at-grade crossings should be Stop-controlled. Additional research should be conducted on crossings that were always Crossbucks-controlled and on crossings that were always Stop-controlled. These crossings may represent two entirely different levels of danger and may operate differently from crossings that were upgraded.

The research reported herein addresses the issues of Stop-sign effects on train-vehicle accidents in the target population of crossings. The NCHRP Report 470 (3) points out that another critical concern of the use of Stop signs is the possible increment of vehicle-vehicle crashes, especially rear-end types. Limited by research scope and data availability, this study focused only on vehicle-train accidents and did not assess the effect of Stop-sign treatment on non-train-related crashes. It is strongly recommended that further studies be conducted to address this issue.

Raub and Lucke (4) did note within their study area that "there was a substantial variation in collision frequencies among the states for a given class of device". It does seem reasonable that regional differences would exist, as well. Additional research is recommended to evaluate Stop-sign efficiency and attributes of significance, generating potentially different prediction models for different areas of the country.

It is recommended that the models generated in part three of this research be used to evaluate existing crossings in their current configuration as well as in potential configuration changes. Those crossings that fall within the beneficial performance range should then be upgraded. Based on specific attributes of the current Crossbuck-only-controlled crossings, decision makers and traffic engineers can use the models to examine accident risks at crossings and assess the potential effectiveness of Stop-sign treatment. This risk-evaluation process may help mitigate crossing accident hazards before vehicle-train accidents occur.

Finally, Stop-sign installations at highway-railroad grade crossings have shown a definite benefit according to the accident record since 1980. The research conducted herein has proved in three different ways that Stop-sign installation safety performance is superior to Crossbucks-only in the target population. The ISTEA mandate to allow usage of Stop signs at highway-railroad grade-crossings has been shown to be correct.

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APPENDICES

Appendix 1: FRA Grade-Crossing Inventory Data Definitions

VARIABLE NAME	DESCRIPTION	ENTERED AS
CROSSING	Crossing No.	Valid Crossing I.D. No. Must be 6 numeric characters followed by 1alphabetic character.
EFFDATE	Effective Date	Entered in form as MM/DD/YYYY (stored in EFFDATE field as YYMMDD)
EDATE	End Date	End date for the most current record is always '999999'. When the crossing is updated with a new record, the end date of the previous current record is set to one day before the effective date of the new current record. EDATE is stored as YYMMDD.
REASON	Reason for Update	1=Changes in Existing Crossing Data, 2=New Crossing, 3=Closed Crossing or Abandoned
STATE	State	Use 2-character state code. Click here to go to Valid State FIPS Code .
CNTYCD	County	Use 4-character county code. Click here to go to Valid County FIPS Code
STATE2	State	Use 2-character state code. Click here to go to Valid State FIPS Code
CITYCD	City	Use 4-character city code. Click here to go to Valid City FIPS Code
NEAREST	In or Near City	0 = In City 1=Near City
RAILROAD	Railroad Operating Company	Valid Railroad Code For valid railroad codes, refer to current list of railroad codes provided by FRA Office of Safety
RRDIV	RR Division	Railroad Division Name or Blank
RRSUBDIV	RR Subdivision	Railroad Subdivision or Blank
HIGHWAY	Highway type and No.	Any Alphanumeric Data or Blank
STREET	Street or Road Name	Any Alphanumeric Data or Blank
RRID	RR I.D. No.	
TTSTN	Nearest RR Timetable Station	Valid Timetable Station
BRANCH	Branch or Line Name	Branch/Line Name or Blank
MILEPOST	RR Milepost	The first two spaces can be alphanumeric, and the next four spaces numeric. There is an implied decimal point after the first 4 characters.
MAPREF	County Map Ref. No.	Any Alphanumeric Data or Blank 1=Pedestrian, 2=Private Vehicle, 3=Public Vehicle (The following is the key for the crossing type and position:
TYPEXING	Type of Crossing	11 - Pedestrian at grade 12 - Pedestrian RR under 13 - Pedestrian RR over 21 - Private at grade 22 - Private RR under 23 - Private RR over 31 - Public at grade 32 - Public RR under 33 - Public RR over)
POSXING	Position of Crossing	1=At grade under 2=RR Under 3=RR over
PRVCAT	Private Xing Category	1=Farm 2=Residential 3=Recreational 4=Industrial 5=Commercial Current Values: 1=signs 2=signals 3=no signs or signals 4=both signs and signals On Previous Version of Inventory Form: 8=Signs 9=Signals 0=None
PRVIND	Signs/ Signals	Any Alphanumeric Data

VARIABLE NAME	DESCRIPTION	ENTERED AS
PRVSIGN	Signs-Specify	(Reference Field 140, PRVSIGNL)
INIT	Initiating Agency	1. =Railroad 2. =State 3.=DOT 4. =Original FRA internal use. Note: 3 & 4 are for internal FRA use only.
BATCH	System coded Field	Coded field, which is used for batch identification during update: The first character is the last character of the year; The second-fourth characters are the day of the year, and the fifth-sixth characters are the sequence number.
USERCD		This field is not currently used No Longer Used Previous: Coded date of update.
UPDATE		Refer to field 105 (UPDATDAT) Not in use1.Used for High Speed Corridor.. Previous Value: 2.This was the link identification code (LIC) from the rail network model for the line on which the crossing lies. The LIC is a five-digit code incorporating the alphabetical abbreviation of the owning railroad and a sequence number.
LINK		Refer to field 89 (HSCORRID)
DAYTHRU	Day Thru Train Movements	0 to 99(Previous Values: 0 to 99) Not in New Form-field No Longer Maintained in Inventory-obsolete
DAYSWT	Switching	(Reference Field135, TOTALTRN, and Field 136 TOTALSWT) (Previous Values: 0 to 99) Not in New Form-field No Longer Maintained in Inventory-obsolete
NGHTTHRU	Night Thru Train Movements	(Previous Values: 0 to 99) Not in New Form-field No Longer Maintained in Inventory-obsolete
NGHTSWT	Night Switching Movements	(Reference Field 135, TOTALTRN, and Field 136 TOTALSWT)
LT1MOV	Less Than One Movement Per Day?	0 = At least one train per day1= Less than one train per day Enter a check if train frequency is less than one train per day.
MAXTTSPD	Maximum Timetable Speed	Values are 1 to 150
MINSPD	From Min:	Values are 1 to 150
MAXSPD	To Max:	Values are 1 to 150
MAINTRK	Main	Values are 0 to 9 for main track
OTHRTRK	Other	Values are 0 to 99 for other tracks
OTHRDES	Specify	Description, if other tracks exist
SEPIND	Does Another RR Operate a Separate Trk. (Y/N)?	1=Yes 2=No
SEPRR	Specify	Up to 4 valid RR codes Code should not be repeated
SAMEIND	Does Another RR Operate Over Your Trk. (Y/N)?	1=Yes 2=No
SAMERR	Specify	Up to 4 valid RR codes Code should not be repeated
WDCODE	Warning Device Code	Highway warning device class at crossing. New Values: 1 - No signs or signals2 - Other signs or signals3 - Crossbucks4 - Stop signs5 - Special Active Warning Devices6 - Highway traffic signals, wigwags, bells, or other activated7. Flashing lights8 - All other Gates9 - Four Quad (full barrier) Gates(Note: SPECPRO (Field 64) has WDCODE=6; and WARNACTO (Field 142) has WDCODE=6).: Previous Values1 - No sign or signal2 - Other signs or signals3 - Stop signs4 - Crossbucks5 - Non-train activated special protection6 - Highway traffic signals, wigwags, or bells7 - Flashing lights8 - Gates(Previous Values: 0 to 9) Not in New Form-field No Longer Maintained in Inventory-obsolete

VARIABLE NAME	DESCRIPTION	ENTERED AS
XBUCKRF	Crossbucks-Reflectorized	(Reference Field 138, XBUCK) (Previous Values: 0 to 9) Not in New Form-field No Longer Maintained in Inventory-obsolete
XBUCKNRF	Crossbucks-Non-reflectorized	(Reference Field 138, XBUCK)
STOPSTD	Highway Stop Signs	0 to 99 represents 9 or more
STOPOTH	Other Stop Sign	Previous Values: (0 to 9, 9 represents 9 or more) Not in New Form-field No Longer Maintained in Inventory-obsolete Conversion: If at least one of the two “Other Signs: Specify” field sets (OTHSGN1 and OTHDES1, or OTHSGN2 and OTHDES2) are blank, the value for STOPOTH (Other Stop Sign) was placed in the blank OTHSGN1 (or OTHSGN2) field, and “OTHRSTPSGN” was entered in the corresponding OTHDES1 (or OTHDES2) field.
OTHSGN1	Other Signs:	0 to 9 9 represents 9 or more
OTHDES1	Specify:	Any Alphanumeric Description
OTHSGN2	Other Signs:	0 to 9 9 represents 9 or more
OTHDES2	Specify:	Any Alphanumeric Description Previous Values: 0 to 9 (9 represents 9 or more) Not in New Form-field No Longer Maintained in Inventory-obsolete
GATERW	Gates-Red & White	(Reference Field 139, GATES) (Previous Values: 0 to 9, (9 represents 9 or more) Not in New Form-field No Longer Maintained in Inventory-obsolete
GATEOTH	Gates-Other	(Reference Field 139, GATES)
FLASHOV	Cantilevered (or bridged) Flashing Lights- Over Traffic Lane	0 to 9 9 represents 9 or more
FLASHNOV	Cantilevered (or bridged) Flashing Lights- Not over Traffic	0 to 9 9 represents 9 or more
FLASHMAS	Mast Mounted Flashing Lights:	0 to 9 9 represents 9 or more
FLASHOTH	Other Flashing Lights:	0 to 9 9 represents 9 or more
FLASHDES	Specify:	Any Alphanumeric Description
HWYSGNL	Hwy. Traffic Signals	0 to 9 9 represents 9 or more
WIGWAGS	Wigwags	0 to 9 9 represents 9 or more
BELLS	Bells	0 to 9 9 represents 9 or more
SPECPRO	Specify Warning Device:	Description of Non-train Activated Device
NOSIGNS	No Signs or Signals	Enter a check if no signs or signals are present. 0=At least one sign or signal 1=No signs or signals
COMPOWER	Commercial Power Available (Y/N)?	1=Yes 2=No
SGNLEQP	Signaling for Train Operation: Is Track Equipped with Train Signals	1=Yes 2=No New Values: 1= Constant Warning Time 2= Motion Detectors 3=DC/AFO 4=other 5=none (Previous Values: 1=Yes 2=No, 3=N/A) Conversion: Yes (1) CWT (1) No (2)-> DC/AFO(3) N/A (3)-> None (5)

VARIABLE NAME	DESCRIPTION	ENTERED AS
SPSEL	Train Detection	(Previous: Does Xing Signal Provide Speed Selection for Trains?) Values are 1 to 5
DEVELTYP	Type of Development	1=Open Space 2=Residential 3=Commercial 4=Industrial 5=Institutional
HWYPVED	Is Highway Paved?	1=Yes 2=No
DOWNST	Does Track Run Down a Street (Y/N)?	1=Yes 2=No
PAVEMRK	Pavement Markings:	Values are 1 to 4 1=Stop lines, 2=RR Xing Symbols, 3=No Markings 4=Stop lines and RR Xing Symbols New Values: 1=Less than 75ft 2=75 to 200ft 3=200 to 500 ft 4=N/A Previous Values: 1=Yes 2=No Conversion: Yes >Less than 75 ft. No >N/A
HWYNEAR	Nearby Intersecting Highway?	(See Field 152, HWYNRSIG)
ADVWARN	RR Advance Warning Signs	1=Yes2=No
XANGLE	Smallest Crossing Angle	1 to 3 (measurement is in degrees) 1=0-29 2=30-59 3=60-90
SURFACE	Crossing Surface:	Conversion: New: 1. Timber 2. Asphalt 3. Asphalt & Flange 4. Concrete 5. Concrete and Rubber 6. Rubber 7. Metal 8. Unconsolidated 9. Other (Specify) Old: 1. Sectional Treated Timber 2.Full Wood Plank 3.Asphalt 4.Concrete Slab 5.Concrete Pavement 6.Rubber 7.Metal Sections 8.Other Metal 9.Unconsolidated 0.Other (Specify) (See Field 151, XSUROTHR)
TRAFICLN	No. of Traffic Lanes Crossing RR:	Values are 1 to 9
TRUCKLN	Are Truck Pullout Lanes Present (Y/N)?	1=Yes 2=No
STHWY1	Is crossing on State	1=Yes

VARIABLE NAME	DESCRIPTION	ENTERED AS
	Highway System (Y/N)?	2=No
HWYSYS	Highway System:	01=Interstate National Highway System 02=Other National Highway System 03=Other Federal-Aid Highway-Not NHS) 08=Non Federal-Aid (NHS=National Highway System)
HWYCLASS	Functional Classification of Road at Crossing:	01, 02, 06, 07, 08, 09, 11, 12, 14, 16, 17, 19 01=R. Interstate, 02=R. Oth. Prin. Arterial, 06=R. Minor Arterial, 07=R. Major Collector, 08=R. Minor Collector, 09=R. Local, 11=U. Interstate, 12=U. Oth. Freeway and Expressway, 14=U. Oth. Prin. Arterial, 16=U. Minor Arterial, 17=U. Collector, 19=U. Local [R=Rural, U=Urban]
AADT	AADT	000001 – 999999 Annual Average Daily Traffic (AADT)
PCTTRUK	Estimate Percent Trucks:	00 – 99 Estimate of % of Trucks
LATITUDE	Latitude	Grade crossing latitudinal coordinate, from the center of the crossing.
LONGITUD	Longitude	Grade crossing longitudinal coordinate, from the center of the crossing.
LLSOURCE	Lat/Long Source	1 = actual 2=estimated Blank=neither 3. Federal Actual 4. Federal Derived –[For FRA Internal Use]
INTRPRMP	Interconnection /Pre-emption	New values: 0 = not interconnected 1 = simultaneous preemption 2 = advance preemption 9 = n/a Previous values: 0 = not interconnected 1 = interconnected 2 = simultaneous preemption 3 = advance preemption 9 = n/a) Conversion: 1. (Interconnected)->1(simultaneous pre.) 2. (simulta. Pre.)->1(simultaneous pre.) 3. (adv.pre.)->2(adv pre.)
HUMPSIGN	Hump Signs	Is Hump crossing sign is installed? 1=Yes 2=No 3=Unknown
HSCORRID	[High Speed] Corridor ID Code	Code must be in High Speed Corridor Table (obtain from FRA)
DOTACPD		DOT Accident Prediction Value
ACPDDATE	DATE	Indicates when DOT ACPD was generated.
ACCCNT1		Accident history – current complete year
ACCCNT2		Accident history – prior year
ACCCNT3		Accident history – two years prior
ACCCNT4		Accident history – three years prior
ACCCNT5		Accident history – four years prior
HISTDATE	DATE	Indicates when ACCCNT1- ACCCNT5 were generated
SCHLBUS	Avg. No of School Buses Passing Over the Crossing on a School Day	Value must be 0 through 999

VARIABLE NAME	DESCRIPTION	ENTERED AS
WHISTBAN	New: Whistle Ban (Quiet Zone)	Valid values: 0=no 1=24 hour 2=partial 9=unknown
PASSCD	Type of Passenger Service	Valid values: A = AMTRAK operates over crossing FLASHDES Specify: 9 C 269 (277) Any Alphanumeric Description B = AMTRAK and other passenger train operates over crossing C = Other passenger train operates over crossing including Seasonal D = None
PASSCNT	Avg Passenger Train Count Per Day	Value must be 0 through 999. [Cannot exceed the total train movements]
RRMAIN	Parent RR	Valid Railroad Code
XINGOWNR	Crossing Owner	Valid Railroad or Company Code This field will indicate the source of the last update.
SOURCE		Valid values: H = other hard copy I = inventory form M = other magnetic media P = mass-update printout T = magnetic tape X = GX O = foreign files
UPDATDAT	DATE	This field will contain the date that the last update to the record was posted.
LONGBDAT	DATE	This field will contain the same date as the field EFFDATE, in this file, except that the year will be four characters in this data element.
LONGEDAT	DATE	This field will contain the same date as the field EDATE, in this file, except that the year will be four characters in this data element
FOURQUAD	Four-quadrant gates present	1=Yes 2=No
TWOQUAD	Two-quadrant gates present	NOT USED IN NEW FORM
OPENPUB	Private Crossing-Public Access	1=Yes 2=No Blank=Unknown
RRNARR1	Railroad Use	These fields will contain whatever the railroad desires to enter.
RRNARR2	Railroad Use	
RRNARR3	Railroad Use	
RRNARR4	Railroad Use	
STNARR1	State Use	These fields will contain whatever the State desires to enter.
STNARR2	State Use	
STNARR3	State Use	
STNARR4	State Use	
AADTYEAR	Year for AADT	This field will contain the year of the last AADT update.
AADTCALC		Not used.
TRAINDAT		Not currently used. Was to contain the year of the last trains update.
TRAINCAL		Not used. (This field was to identify how the last trains update was calculated: 1 = actual 2 = estimated Blank = neither)
RESERVE1	Reserved for Future Use	Reserved for future use. (RESERVE1 is 1 C. RESERVE2,

VARIABLE NAME	DESCRIPTION	ENTERED AS
		RESERVE3, RESERVE4, and RESERVE5 are 3 C each.)
RESERVE2	Reserved for Future Use	
RESERVE3	Reserved for Future Use	
RESERVE4	Reserved for Future Use	
RESERVE5	Reserved for Future Use	
DOTCASPD		DOT Predicted Casualty Rate
DOTFATPD		DOT Predicted Fatality Rate
FUNCCAT		Not Used.
RRCONT	Railroad Contact	This field contains the telephone number of the railroad contact associated with the crossing.
HWYCONT	State Contact	This field contains the telephone number of the State highway contact associated with the crossing.
POLCONT	Emergency Contact	This field contains the telephone number of the emergency contact associated with the crossing. Normally, this will be the ENS telephone number posted at the crossing or along the railroad branch line.
NARR	Narrative	No editing will be done on this field
TOTALTRN	Total Trains	0-500 Conversion: TOTALTRN = (DAYTHRU + DAYSWT + NGHTTHRU + NGHTSWT)
TOTALSWT		0-500 Conversion: TOTALSWT = DAYSWT + NGHTSWT
ENSSIGN	ENS Sign	1 = Yes 2 = No
XBUCK	Crossbucks	Conversion: XBUCK = XBUCKRF + XBUCKNRF
GATES	Gates	Conversion: GATES = GATERW + GATEOTH
PRVSIGNL	Signals -Specify	Conversion: If PRVIND = 2 then previous PRVSIGN value will be moved to PRVSGNL. (Refer to field 24 (PRVSIGN)
FLASHPAI	Number of flashing light pairs	This field contains the number of flashing light pairs.
WARNACTO	Other Train Activated Warning Devices	This field contains other train activated warning devices.
CHANNEL	Channelization Devices with Gates	1=All Approaches 2=One Approach 3=None
XINGADJ	Adjacent Xing with separate no.?	1=Yes 2=No
XNGADJNO	Adjacent Xing with separate no.? Provide no.	Valid crossing number
ILLUMINA	Is Xing Illuminated?	1=Yes 2=No
HWYSPEED	Posted Hwy Speed	This field contains the posted highway speed.
CNTYNAM	County	Valid County Name
TTSTNNAM	Nearest RR Timetable Station	Valid Timetable Station name
CITYNAM	City	Valid City Name
XSUROTHR	Crossing Surface:	Specify Other Crossing Surface
HWYNRSIG	Other Nearby Intersecting Highway? Is it signalized?	1=Yes 2=No

Appendix 2: Track Classification

Classes of track are defined in the Federal Track Safety Standards (49 CFR Part 213). See 49 CFR 213.4 and 213.9. Excepted track should be entered as Class X.

	Maximum Speed	
Track Class	Freight Trains	Passenger Trains
X	10	Prohibited
1	10	15
2	25	30
3	40	60
4	60	80
5	80	90
6	110	110
7	125	125
8	160	160
9	200	200

Appendix 3: Odds and Odds Ratio

Probabilities and odds are natural ways to quantify the chances of an event happening. The odds of an event is the expected number of times an event will occur to the expected number of times it will not occur.(45) Therefore, probability and odds are related as shown in Equations 3-1 and 3-2:

$$O = \frac{p}{1-p} \quad \text{(Eq. 3-1)}$$

$$p = \frac{O}{1+O} \quad \text{(Eq. 3-2)}$$

Where:

O = Odds of an event

p = Probability of an event

$1\text{-}p$ = Probability of event not occurring

The odds compare the probability of an accident occurring at a Stop sign compared to Crossbuck for a given category. For example, the odds of an accident occurring at a stop sign (compared to a Crossbuck) when the AADT is ≤ 500 vehicles per day, or the odds of an accident occurring at a Stop sign (compared to a Crossbuck) when the AADT is >1000 vehicles per day.

Consider Equation 3-2 in regard to the two passive controls being evaluated. If the numerator is the probability of an event occurring, then the denominator is the probability of an event not occurring at a Stop sign which means at a Crossbuck–only crossing. For example, if the event being considered is accidents that occurred during the daytime, the odds measures the probability of daytime accidents to occur at Stop signs compared to Crossbucks-only.

This brings us to the odds ratio, a widely used measure of the relationship between dichotomous variables.(45) It is simply the odds of an event for one category divided by the odds of the event for another category. For example, in Equation 3-3 the odds of an accident occurring in the daylight compared to the odds of an accident occurring at night, for Stop signs compared to Crossbucks-only.

$$OddsRatio = \frac{\left(\dfrac{p_{Sd}}{1-p_{Sd}}\right)}{\left(\dfrac{p_{Sn}}{1-p_{Sn}}\right)} = \frac{\left(\dfrac{p_{Sd}}{p_{Xd}}\right)}{\left(\dfrac{p_{Sn}}{p_{Xn}}\right)} = \frac{\left(\dfrac{p_{Sd}}{p_{Sn}}\right)}{\left(\dfrac{p_{Xd}}{p_{Xn}}\right)} \qquad \text{(Eq. 3-3)}$$

Where:

$OddsRatio$= measure of the relationship between daytime/nighttime accidents for Stop- and Crossbuck-only controlled crossings

p_{Sd} = Probability of an accident occurring during daylight at a Stop sign

p_{Sn} = Probability of an accident occurring during night at a Stop sign

p_{Xd} = Probability of an accident occurring during daylight at a Crossbuck-only

p_{Xn} = Probability of an accident occurring during night at a Crossbuck-only

The odds ratio compares the odds of an accident occurring for different sub categories, i.e., the propensity for an accident in one subcategory compared to another subcategory. For example, the odds of an accident occurring at a Stop sign when the AADT is >1000 vehicles per day compared to the odds of an accident occurring at a Stop sign, when the odds for each category are described as illustrated above.

Appendix 4: Poisson Model and Negative-Binomial Model

The most widely used model for count data analysis is Poisson regression. The Poisson probability model is shown in Equation 4-1. In this research it is interpreted as the probability, $P(k_i)$, of having a specified number (count) of accidents (k) at a specific crossing (i) during the control period (Δt) in which the crossing was either Crossbuck- or Stop-controlled.

$$P(k_i) = \frac{e^{-\lambda_i} \lambda_i^{k_i}}{k_i!} \qquad \text{(Eq. 4-1)}$$

Where:

k_i = A variable indicating how many times an event has occurred in regard to instance i, such as accident counts at crossing i

λ_i = The Poisson parameter, equal to the distribution mean and also the variance (var $(k_i) = \lambda$)

The Poisson regression is fitted to the data by specifying the Poisson parameter λ_i to be a function of the explanatory variables as indicated in Equation 4-2.

$$\ln(\lambda_i) = \beta X_i \qquad \text{(Eq. 4-2)}$$

Where:

λ_i = The Poisson parameter

X_i = Independent variables

β = Model coefficient

Using standard maximum likelihood methods, the Poisson regression can then be estimated using the likelihood function $\mathscr{L}$ in Equation 4-3.

$$\mathscr{L}(\beta) = \prod_i \frac{\exp[-\exp(\beta X_i)][\exp(\beta Xi)]^{n_i}}{n_i!} \qquad \text{(Eq. 4-3)}$$

However, the Poisson model, as noted in Equation 4-2, is predicated on the variance being equal to the mean, an equi-dispersion. Shankar, et al., (46) suggests that, from a large body of literature, most accident data are likely to be overdispersed. When the variance is not equal to the mean, the data is considered overdispersed or underdispersed and can result in biased coefficients, similar to heteroscedasticity in ordinary least-squares models. The null hypothesis of equi-dispersion should then be tested to determine if the Poisson model is appropriate.

In the event that the data is, in fact, overdispersed as Shankar, et al., (46) suggests, the null hypothesis should be rejected and the Poisson model would be inappropriate for this analysis. However, Shankar, et al., (46) go on to point out that this limitation can be readily overcome by use of a variant of the Poisson model, known as the negative-binomial model. The negative binomial introduces an error term ε_i to Equation 4-2 to account for the bias cased by the overdispersion as shown in Equation 4-4.

$$\ln(\lambda_i) = \beta X_i + \varepsilon_i \qquad \text{(Eq. 4-4)}$$

Introducing this term allows the formulation of a new model, the negative-binomial model, which allows the variance to be different from the mean in such a way as shown in Equation 4-5.

$$\text{var}(k_i) = E(k_i)[1 + \alpha E(k_i)] \qquad \text{(Eq. 4-5)}$$

Where:

$E(k_i)$ = Expected value of accident counts at crossing i

α = Measure of the dispersion, equal to the variance of the error term (gamma distributed rather than normally distributed in the case of the Poisson model)

VITA

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